THE USE OF A LOWER-LIMB PROSTHETIC DEVICE TO IMPROVE PERFORMANCE FACTORS IN ELITE PARACANOE

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The current study examined how a lower-limb prosthesis affected paracanoe performance factors. One paracanoe athlete completed two, 30 second tethered sprints with and without the use of a custom prosthesis. Kinematic and kinetic performance variables were compared. When the prosthesis was worn, a significant increase in propulsion impulse was observed on the right side (50 Ns to 61 Ns), which may have been due to enhanced contact between the residual limb and the kayak. Stroke rate symmetry index became significantly more symmetrical while wearing the prosthesis (0.27 to 0.01); perhaps due to a more upright trunk position, decreasing variability in center of gravity movement. In conclusion, based on the results, the addition of a prosthesis for the paracanoe athlete in the present study had a positive effect on performance factors.

KEYWORDS: Propulsive Impulse, Stroke Length, Symmetry, Case Study

INTRODUCTION: Sprint kayak performance is determined by the time taken to cover a prescribed distance of 200m, 500m or 1000m (Time = Velocity*Distance). The Wainwright, Cooke, & Low (2016), sprint kayak deterministic model, shows the key determinants that of kayak velocity are stroke distance and stroke time which can be further broken down into forward and backward reach, and pull time. When a kayaker takes a stroke, the three phases (pull, vertical, and release) each effect the total outcome of stroke velocity. The third phase (release) has the greatest effect on the propulsive force which generates the maximum velocity (Wainwright et al., 2016). There are a number of opposing factors related to this force production at the release of the stroke, including asymmetry, yaw, pitch and roll (Michael, Smith, and Rooney, 2009). To reduce wasted energy and movement of the kayak, the athlete must become as mechanically efficient and symmetrical as possible when performing each stroke.

Many of the key deterministic factors related to performance in able-bodied sprint kayak are also critical for success in paracanoe. Paracanoe, as defined by the International Canoe Federation (ICF) is a 200 meter canoeing discipline that uses two types of boats, kayak and va'a, and is specific for athletes with an impairment (International Canoe Federation, 2018a). Athletes in the sport compete against other athletes with the same impairment classifications, KL1, KL2, or KL3. An athlete with a KL1 classification has no or limited trunk function and no leg function. KL2 athletes have partial trunk and leg function, have limited leg movement during paddling, and are able to sit upright in the kayak, with the potential to need a special backrest. KL3 athletes have normal trunk function and partial leg function, are able to sit with the trunk in forward flexion, and are able to use at least one leg or prosthesis (International Canoe Federation, 2018b).

Adaptations to kayak equipment for paracanoe athletes can vary depending on individual impairment (KL1 - 3). Kayak setup is generally based on trial and error (Ong et al., 2005), where athlete comfort is prioritized over mechanical efficiency as the primary goal (Broomfield & Lauder, 2015). However, mechanical efficiency is comparably important in elite level competition and is arguably more difficult for paracanoers to achieve with their personal needs when comfort is prioritized (Pensgaard & Sorensen, 2002). Whiting and Varrette (2012) suggested that the lumbar back, hips, thighs, knees, toes, and gluteal region are all necessary contact points to possess full control over a kayak. However, many paracanoers cannot meet all contact point requirements due to lower limb absence. Asymmetrical lower limb mechanics are an inevitable byproduct of this absence, which may lead to ineffective forward propulsion and asymmetrical joint angles during each stroke (Limonta et al., 2010, Dieffenbach, Murray,

& Zakrajsek, 2011). This suggests that some form of prosthetic limb or technological adaptation may be essential to achieve mechanical efficiency and symmetry.
Research on assistive technology in sprint kayaking and its subsequent effect on performance is limited. Therefore, the purpose of this study was to determine how the use of a lower-limb prosthesis affects paracanoe performance factors in a KL3 athlete.

METHODS: This case study was conducted as part of a problem based learning course in the Exercise Science Program at Northern Michigan University. For this case study, a 26 year old female (height = 1.78 m) with Proximal Femoral Focal Deficiency - Type D was observed. The participant is a paracanoeist under KL3 classification. Prior to testing day, a custom prosthetic was designed, built, and fitted for the participant by her primary prosthetist.
On testing day, the participant was placed in a lap pool in a 14 ft Eddyline Samba kayak and completed a 10 minute warm-up, paddling at a self-selected pace. Following warm-up, the kayak stayed in the water and was attached to the force platform (detailed below) and the participant was given instructions on the testing protocol. Before testing began, the participant completed two 10-second familiarization trials at a moderate pace in the baseline condition and two 10-second familiarization trials following fitting of the prosthetic. The participant then completed two sprints at baseline and two sprints with the custom prosthetic, for a total of four trials. Each sprint lasted 30 seconds and was followed by 15 minutes of rest (Berg, 1982; Tomlin & Wenger, 2001).
Testing setup included three high-speed digital cameras, with one camera on each side to capture left and right sagittal plane motion and one camera set up directly behind the participant to capture the frontal plane motion. The cameras collected the participant's movement at 60, 240, and 320 frames per second (fps), located behind, on the right side, and on the left side of the participant, respectively (Mann & Kearney, 1980). The bow of the kayak was attached to an AMTI force platform (Watertown, MA, USA) via a metal cable to measure peak propulsion.
Kinematic variables measured were sagittal shoulder angle at catch, sagittal trunk angle at catch and release, sagittal trunk range of motion (ROM), lateral trunk flexion at catch and release, lateral trunk flexion ROM, stroke rate, paddle angle at catch, paddle water and air time, and paddle pull time (catch to vertical). All angles were absolute, measured from the horizontal. Kinetic variables that were measured were peak propulsion force and propulsion impulse. Kinovea (v. 0.8.15; Kinovea Open Source Project) was used to analyze 2D video data, with key events marked at paddle catch, paddle vertical, and paddle release. For kinematic variables, strokes 5-15 of each trial were used and averaged during baseline and prosthetic conditions. Differences between right and left side were calculated using a standard symmetry equation, with a value of zero representing full symmetry. Microsoft Excel (v. 2016; Redmond, WA, USA) was used to calculate peak propulsion and impulse of each stroke, with values averaged across trials, and to compare baseline and prosthetic conditions using paired t-tests. Significance level was set at $P < 0.05$.

RESULTS: Propulsion impulse on the right significantly increased from 50 Ns at baseline to 61 Ns while wearing the prosthesis, while the bilateral symmetry of the propulsion impulse became closer to symmetrical changing from 0.30 to 0.15. The shoulder angle at catch exhibited less flexion on both the right and left side during the prosthesis condition, showing decreases from 31° to 35° and from 26° to 29°, respectively. Additionally the participant sat in a significantly more upright position at catch and release on both sides (Table 1). Further, both paddle air time and stroke rate became significantly more symmetrical in the prosthetic condition by decreasing the symmetry index from 0.17 to 0.03 and 0.27 to 0.01, respectively. Refer to Table 1 for mean and standard deviation values and significance levels for all measured variables.

Table 1. Values reported as mean ± standard deviation.

Variable	Baseline		Symmetry Index	Prosthetic		Symmetry Index
	Right	*Left*		*Right*	*Left*	
Shoulder angle at catch (°)	30.9 ± 4.0	26.3 ± 3.3	0.16	34.8 ± 3.6*	28.9 ± 4.8*	0.19
Sagittal trunk angle at catch (°)	62.3 ± 3.1	58.5 ± 5.2	0.06	69.1 ± 3.0**	63.9 ± 3.4**	0.08
Sagittal trunk angle at release(°)	74.6 ± 3.1	77.2 ± 4.3	0.03	81.1 ± 3.7**	81.6 ± 4.6*	0.01
Sagittal trunk angle ROM (°)	12.4 ± 5.3	18.7 ± 6.5	0.40	12.0 ± 5.4	17.7 ± 3.9	0.45
Lateral trunk flexion at catch (°)	105.4 ± 3.7	101.0 ± 2.8	0.04	105.2 ± 4.4	96.1 ± 2.7**	0.09**
Lateral trunk flexion at release(°)	88.4 ± 11.7	83.1 ± 13.2	0.04	82.3 ± 2.3*	75.5 ± 3.9*	0.17
Lateral trunk flexion ROM (°)	17.0 ± 9.8	17.9 ± 11.7	0.04	23.0 ± 4.2*	20.6 ± 4.0	0.17
Paddle angle at catch (°)	39.3 ± 2.3	40.0 ± 3.3	0.02	39.6 ± 3.0	39.7 ± 2.8	0.00
Paddle water time (s)	0.55 ± 0.09	0.59 ± 0.08	0.07	0.52 ± 0.07*	0.54 ± 0.07*	0.04
Paddle air time (s)	1.03 ± 0.06	1.27 ± 0.32	0.17	1.05 ± 0.07	1.02 ±0.07**	0.03**
Paddle pull time (s)	0.19 ± 0.03	0.35 ± 0.06	0.58	0.16 ± 0.03**	0.34 ± 0.06	0.70**
Stroke rate (strokes/sec)	0.66 ± 0.19	0.61 ± 0.22	0.27	0.64 ± 0.04	0.65 ± 0.04	0.01**
Peak propulsion force (N)	300.37 ± 77.51	316.05 ± 53.61	0.07	295.23 ± 75.55	297.78 ± 51.84	0.02
Propulsion impulse (Ns)	50.49 ± 12.18	66.80 ± 16.08	0.30	61.35 ± 14.93*	69.24 ± 16.65	0.15

** Significant at P = 0.05 compared to baseline*
*** Significant at P = 0.001 compared to baseline*

DISCUSSION: The purpose of this study was to determine how the use of a lower-limb prosthesis affects paracanoe performance factors in a KL3 athlete. With the addition of a prosthesis, the main effects were an increase in unilateral propulsion impulse and improvement in stroke rate symmetry.

When the prosthesis was implemented on the left side the athlete produced more propulsive impulse on the right side and decreased in lateral trunk flexion on the left side. The athlete may have been leaning more during baseline due to lack of support from the residual limb. Because the hip, thigh, and toes are important points of contact that allow an athlete to maintain control of the kayak (Whiting and Varrette, 2012), the addition of the prosthesis may have helped the athlete to lean less by providing support against the side and bottom of the kayak. The additional points of contact to the kayak facilitated by the prosthetic may also be related to the enhanced propulsion impulse as there is a direct relationship between force produced on the blade of the paddle and the force produced at through the legs (Michael et al., 2009).

Plagenhoef (1979) proposed that the best paddlers produce a rhythmic rather than a fast stroke rate. In the present study stroke rate became significantly more symmetrical with the addition of the prosthesis, suggesting a less rhythmic stroke rate at baseline. In addition, significant increases in sagittal trunk angle at catch and release suggest that the athlete became more upright while wearing the prosthetic. This upright position suggests that there may be less variation in the athlete’s center of gravity, a reduction in these unwanted trunk movements would improve stroke efficiency and may have resulted in a more symmetrical stroke rate (Mann & Kearney, 1980).

In the present study, the athlete performed two, 30 second work trials for each condition in a non-randomized order with the final trials being in the prosthetic condition. The athlete sat stationary in her kayak for 15 minutes rest between trials. Signorile and colleagues (1993), report that fatigue is likely when two or more high intensity work cycles are completed consecutively. It is possible that the athlete in the current study may have been experiencing fatigue during the finals trials when wearing the prosthesis. The use of active recovery between trials and conditions may have helped to avoid fatigue and improve the athlete’s performance during the latter stages of the study. Fatigue and the absence of active recovery periods are limitations of the current study, and may have adversely influenced the data collected in the prosthetic condition.

Another potential limitation of the current study was that the kayak had to be held stationary during trials in both conditions. The pool used in this study was not large enough for the athlete to accelerate to competition speed, paddle forward for 30 seconds, and then decelerate. The stern of the kayak was connected to a force plate, and the bow was held stationary by a research team member to keep it from deviating from perpendicular to the force plate. Holding the kayak may have affected the degree of yaw, pitch, and roll that it exhibited, and since an athlete naturally shifts their body mass to maintain stability during these conditions, related factors like lateral trunk flexion may have been affected.

CONCLUSION: The purpose of this study was to determine how the use of a lower-limb prosthesis affects paracanoe performance factors in a KL3 athlete. Results indicate a significant unilateral increase in propulsion impulse and a significant improvement in stroke rate symmetry. The addition of the prosthesis may have allowed the residual limb to have more contact with the kayak, potentially resulting in greater force production. Stroke rate became more symmetrical while wearing the prosthesis and the athlete maintained a more upright position, which may have helped to stabilize their center of gravity, resulting in a more rhythmic and efficient stroke. It should be noted that fatigue and the absence of an active recovery period may have adversely influenced data in the prosthetic condition. In conclusion, the addition of a prosthesis for the paracanoe athlete in the present study had a positive effect on performance factors, and it is recommended that the athlete extensively practice with the prosthesis to become accustomed to it and modify if needed, and eventually compete while wearing it.

REFERENCES

Berg, K. (1982). Anaerobic conditioning: Training the three energy systems. *NSCA Journal*, 48-50.

Broomfield, S. A., & Lauder, M. (2015). Improving paddling efficiency through raising sitting height in female white water kayakers. *Journal of sports sciences*, *33*(14), 1440-1446.

Dieffenbach, K. D., Murray, M., & Zakrajsek, R. (2011). The Coach Education Internship Experience: An Exploratory Study. *International Journal of Coaching Science*, *5*(1).

International Canoe Federation. (2018a). Paracanoe. Retrieved January 8, 2019, from https://www.canoeicf.com/discipline/paracanoe

International Canoe Federation. (2018b, August 19). ICF Paracanoe Kayak Classifiers' Manual.

Limonta, E., Squadrone, R., Rodano, R., Marzegan, A., Veicsteinas, A., Merati, G., & Sacchi, M. (2010). Tridimensional kinematic analysis on a kayaking simulator: key factors to successful performance. *Sport Sciences for Health*, *6*(1), 27-34.

Mann, R., & Kearney, J. (1980). A biomechanical analysis of the Olympic-style flatwater kayak stroke. *Medicine and Science in Sports and Exercise*, *12*(3), 183–188.

Michael, J. S., Smith, R., & Rooney, K. B. (2009). Determinants of kayak paddling performance. *Sports Biomechanics*, 8(2), 167–179.

Ong, K. B., Ackland, T. R., Hume, P. A., Ridge, B., Broad, E., & Kerr, D. A. (2005). Kayak: equipment set-up among Olympic sprint and slalom kayak paddlers. *Sports Biomechanics*, *4*(1), 47-58.

Pensgaard, A. M., & Sorensen, M. (2002). Empowerment through the sport context: A model to guide research for individuals with disability. *Adapted Physical Activity Quarterly*, *19*(1), 48-67.

Plagenhoef, S. (1979). Biomechanical analysis of olympic flatwater kayaking and canoeing. *Research Quarterly. American Alliance for Health, Physical Education, Recreation and Dance*, *50*(3), 443–459.

Signorile, J. F., Tremblay, L. M., & Ingalls, C. (1993). The effects of active and passive recovery on short-term, high intensity power output. *Canadian Journal of Applied Physiology*, *18*(1), 31–42.

Tomlin, D. L., & Wenger, H. A. (2001). The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports Medicine*, 31(1), 1–11.

Whiting, K., & Varette, K. (2012). *Whitewater kayaking: the ultimate guide*. Heliconia Press.

Wainwright, B., Cooke, C., & Low, C. (2016). Performance related technique factors in olympic sprint kayaking. *ISBS-Conference Proceedings Archive*, *33*(1).

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