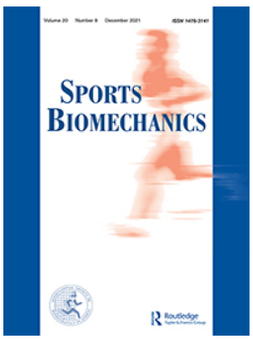

Sports Biomechanics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rspb20

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To cite this article: Molly L. Tilden, Avleen R. Oberoi & James M. Wakeling (2021): Canoe slalom C1 stroke technique during international competitions, Sports Biomechanics, DOI: 10.1080/14763141.2021.1942968

To link to this article: https://doi.org/10.1080/14763141.2021.1942968

SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2021.1942968

Canoe slalom C1 stroke technique during international competitions

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ABSTRACT

The purpose of this study was to compare the frequency and duration of on-side and off-side strokes and stroke transitions between male and female canoe slalom athletes during international competitions. We analysed 33 International Canoe Federation World Cup, World Championship and European Canoe Association Championship canoe slalom race videos, from 2018 to 2020, frame-by-frame. We recorded drive durations and transition durations for each race run. We also recorded the frequency of different stroke types and transition types used in each run. Stroke timing parameters differed between female and male athletes. We found that female athletes performed a significantly greater proportion of switch transitions and on-side strokes. Male athletes performed a significantly greater proportion of cross transitions and off-side strokes. Male athletes performed significantly faster cross transitions. On-on and off-off transition durations were significantly faster than cross transitions, and cross transitions were significantly faster than switch transitions. Females had a significantly longer drive duration and lower stroke frequency compared to males. Overall, stroke and drive durations of on-side strokes and off-side strokes were not significantly different. This study identifies stroke technique differences between male and female canoe slalom athletes which can be used as a basis for future research and training.

ARTICLE HISTORY
Received 16 December 2020
Accepted 2 June 2021

KEYWORDS
White-water padding; paddle sport; C1M; C1W; video analysis

Introduction

Men's canoe slalom (C1M) became an official Olympic event in 1992, and women's canoe slalom (C1W) is set to become an Olympic event at the Tokyo 2020 Games. As the sport attains gender equity, it presents a timely opportunity to study how C1 technique differs between male and female athletes.

Canoe slalom originated in Switzerland in 1933 as a summer alternative to slalom skiing and athletes initially competed on a flatwater course (International Canoe Federation [ICF], 2019). Today's athletes race down a white-water course while navigating green hanging gates in a downstream direction, or red gates in an upstream direction. Each slalom course is different: they are up to 300 m long and contain a maximum of 25 gates, with at least six red upstream gates. Officials design the courses to test an athlete's

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ability to maintain boat trajectory, speed, and balance, with leading athletes completing them in 90–110 s (ICF, 2019). Canoe slalom competitions have two types of boat: a canoe (C1W and C1M) where the athletes use a single-bladed paddle, and a kayak (K1W and K1M) where the athletes use a double-bladed paddle. Several studies exist on kayak K1 stroke technique, but few articles explore C1 stroke technique; the few articles that investigate C1 stroke technique look exclusively at male athletes (Hunter et al., 2007, 2008). The purpose of this study was to evaluate differences in stroke technique between male C1M and female C1W athletes.

The standard canoe stroke is an *on-side* stroke where the top arm, that holds the t-grip, crosses the athlete's body, and the paddle stroke occurs on the same side of the boat as the bottom arm that holds the paddle shaft (Figure 1; Hunter et al., 2007). Athletes can perform on-side strokes on the dominant side of the boat (the athlete's left side in Figure 1), which is the most frequently used side for each athlete, or the non-dominant side (the athlete's right side in Figure 1). By contrast, for an *off-side* stroke, the bottom arm crosses the body and the paddle is placed on the opposite side of the boat (Figure 1; Hunter et al., 2007). A canoe stroke is broken up into a *drive phase*, when the paddle applies propulsive force on the water, and a *transition phase*, when the paddle is either out of the water or no longer applying propulsive force on the water and is moved back to the start of the next drive phase. Together, the drive phase and transition phase comprise the total *stroke duration*.

An athlete can transition from an on-side stroke to another on-side stroke on the same side, which we call an *on-on* transition. An athlete can transition from an off-side stroke to another off-side stroke on the same side, which we call an *off-off* transition. An athlete can transition from an on-side stroke to an off-side stroke, or vice versa, which we call a *cross* transition. Finally, an athlete can transition from an on-side stroke on one side of the boat to an on-side stroke on the other side, which we call a *switch* transition (Figure 1).

Athletes transition their paddle blade to their non-dominant side to successfully negotiate some gates (particularly upstream gates), or to provide stability crossing some water features (such as 'stoppers' or 'hydraulics') and can do this in one of two ways. They can *cross* the paddle blade to the other side of the boat while leaving their hands gripped on the paddle shaft in the same positions, resulting in an off-side stroke (Figure 1). Male athletes traditionally use off-side strokes when they paddle on their non-dominant side. Alternatively, athletes may *switch* their hand positions on the paddle shaft as they move the blade across the boat, so they still perform an on-side stroke (Figure 1), but this is now an on-side stroke on the non-dominant side. The different transition phases are illustrated in Figure 1.

Traditionally, male athletes specialised in the C1 event and trained and raced using cross transitions. Female athletes raced C1W for the first time in the World Championships in 2011 and they introduced the switching technique to international competition: female athletes previously trained and raced in kayak K1W where they routinely paddled on different sides with some similarity to the symmetry of the switching technique. In 2014, a male athlete broke tradition when he performed the switching technique during his race and won the C1M World Cup (he had also previously raced kayak K1M: Busta, 2020).

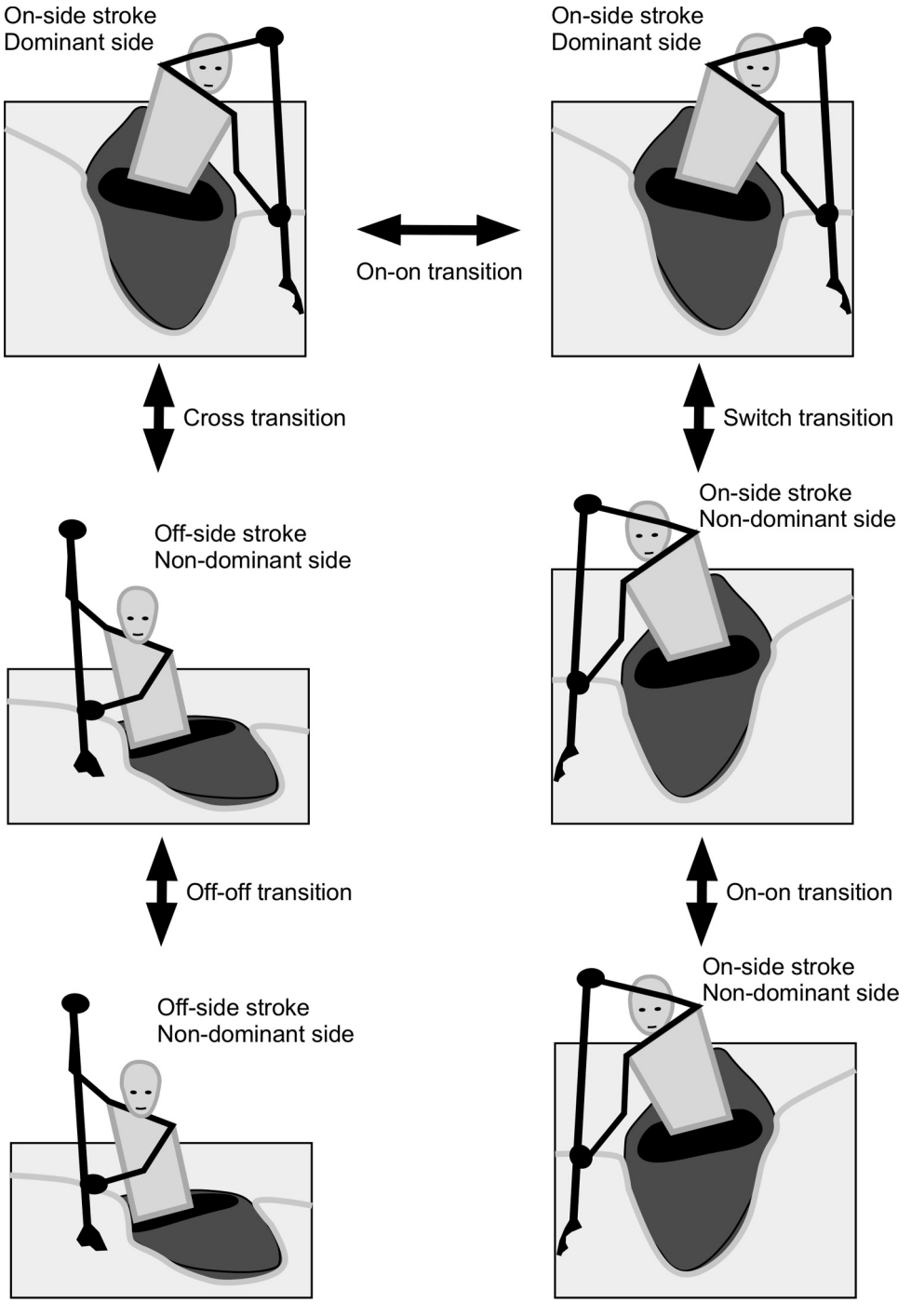

Figure 1. Illustration of the different stroke types and transition types. The athlete shown has their dominant side determined by paddling on-side strokes to the left of the boat. All combinations of stroke and transition types observed in this study are shown.

Currently, some athletes use a combination of off-side strokes and switching, whereas other athletes use one technique exclusively. Athletes that use both techniques may occasionally perform an off-side stroke on their dominant side, but, most often, they perform off-side strokes on their non-dominant side.

Before C1W became an international event, Hunter et al. (2008) used video analysis to characterise canoe slalom technique for K1M, K1W and C1M canoe slalom events. They found that C1M athletes took significantly fewer strokes per race than K1M athletes and that 71% of C1M strokes were forward strokes (Hunter et al., 2008). Specifically, C1M athletes performed off-side strokes at a lower frequency and with longer drive durations than on-side strokes (Hunter et al., 2008). Because C1W only recently became an event in international competition, systematic comparisons between C1W and C1M technique have yet to be made. The comparison between C1M and C1W techniques provides an opportunity to evaluate differences between the cross and switching transitions, which may be useful for future training and coaching.

The purpose of our study is to compare the on-side and off-side stroke and transition durations, and frequencies of different types of strokes between C1W and C1M slalom athletes during international competitions. We hypothesised that C1W athletes use the switching technique more frequently than C1M athletes. We also expected that off-side strokes would have longer drive durations than on-side strokes, following the findings from Hunter et al. (2008) study.

Methods

We selected runs from semi-final and final races in international competitions: ICF World Cup, ICF World Championship and European Canoe Association Championships between 2018–2020 (Table 1). We targeted the race selection to include four C1M athletes who switched, and one C1W athlete who exclusively crossed so that both stroke types were represented by both sexes. Preference was given to race runs that did not incur 50-second penalties (for missing gates), however, we had to select 4 runs that included these penalties so that we could identify sufficient switching transitions for C1M and cross transitions for C1W. We analysed data from 8 C1W slalom athletes (20 to 26 years old) and 11 C1M slalom athletes (20 to 41 years old) competing in a total of 33 race runs. The analysed videos and athletes' information lie in public domain of YouTube, therefore, this study did not require ethical approval or informed consent from the athletes.

The videos were available in 25 frames per second, giving a 0.04 s interval between frames. A single evaluator analysed all the video footage using a frame-by-frame

Table 1. Races analysed.

	C1M	C1W
Races	2018 World Championship Final (Rio, BR)	2018 World Championship Semi-Final (Rio, BR)
	2018 World Championship Semi-Final (Rio, BR)	2018 World Cup 1 Final (Liptovsky, SK)
	2019 ECA European Championships Semi-Final (Pau, FR)	2018 World Cup 2 Semi-Final (Krakow, PL)
	2019 ECA European Championships Final (Pau, FR)	2019 World Cup 1 Semi-Final (Lee Valley, EN)
	2020 ECA European Championships Final (Prague, CZE)	
	2020 ECA European Championships Semi-Final (Prague, CZE)	

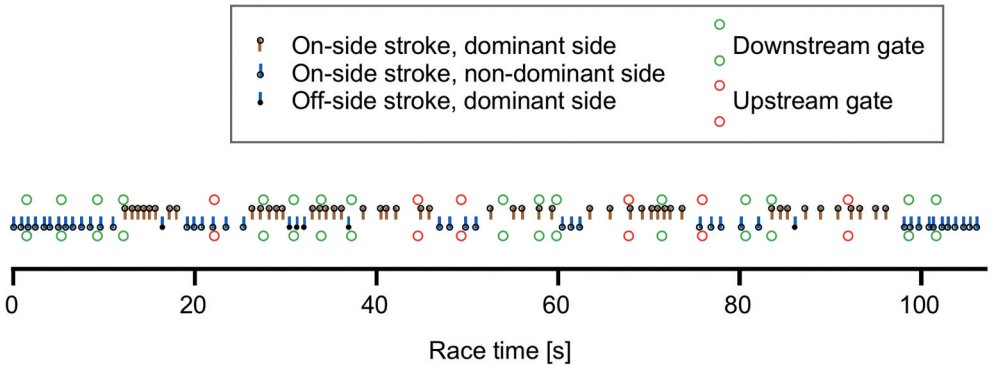

Figure 2. Raw stroke data analysed from one run on a race final. The race time is shown across the page, downstream gates ate shown by green circles, and upstream gates by red circles. Paddle strokes are shown by symbols, with the left side being the dominant side for this athlete.

analysis tool. The evaluator watched the videos and recorded the time for the start of and end of the drive phase (termed 'paddle in time' to 'paddle out time', respectively by Hunter et al., 2007), with the drive phase being the period when the blade exerted pressure on the water. If the blade was moved to a new location without pressure on the blade then a new stroke was counted, even if the blade did not leave the water (Hunter et al., 2007) and this occurred during off-off transitions due the athletes' natural inability to remove the paddle from the water during off-off transitions. The evaluator recorded transition duration as the time between the end of one drive phase and the start of the next. Stroke duration was the total time for the drive phase and subsequent transition phase. Note that as the stroke duration contains both drive and transition phases, comparisons between strokes may be less distinct. However, we reported the separate times for the drive and transition phases for a more detailed comparison. The evaluator recorded whether each stroke was an on-side or off-side stroke, and which side of the boat the paddle was placed for the drive phase. The evaluator analysed all strokes that were visible on the race course and included both strokes performed to negotiate gates as well as the strokes to move between gates A typical sequence of strokes, relative to the race time and slalom gates, can be seen in Figure 2.

Intra-rater reliability is a measure of how consistent the evaluator measures timing from these race videos. The evaluator analysed the same video five times to assess intra-evaluator reliability: we compared the strokes between all five evaluations, and the mean standard deviation for the estimates of drive start-times and end-times was 0.04 s. This intra-rater reliability exceeds previously reported reliability for canoe slalom technique (Hunter et al., 2007).

We calculated the proportion of each stroke type and transition type for each run and compared these proportions between C1W and C1M using non-parametric Mann-Whitney U tests. We compared the effect of stroke type and sex on the stroke and transition times using GLM ANOVA (with Box-Cox transforms to satisfy normality assumptions) using athlete ID, sex, stroke/transition type and stroke side as factors. *Post hoc* Tukey tests distinguished between the factors. Statistical tests

were considered significant at $p < 0.05$ (Minitab v19, Minitab Inc., State College, PA, USA).

Results

We analysed a total of 3,116 paddle strokes. C1W athletes performed a significantly greater proportion of on-side strokes and non-dominant side strokes than C1M athletes. In contrast, C1M athletes performed a significantly greater proportion of off-side strokes and dominant side strokes than C1W athletes (Figure 3, Table 2).

Overall, there was a significant main effect of athlete sex on the stroke and drive durations: in particular the C1W athletes had significantly longer stroke (1.16 s) and drive (0.63 s) durations than the C1M athletes (1.01 s and 0.54 s, respectively; Figure 4,

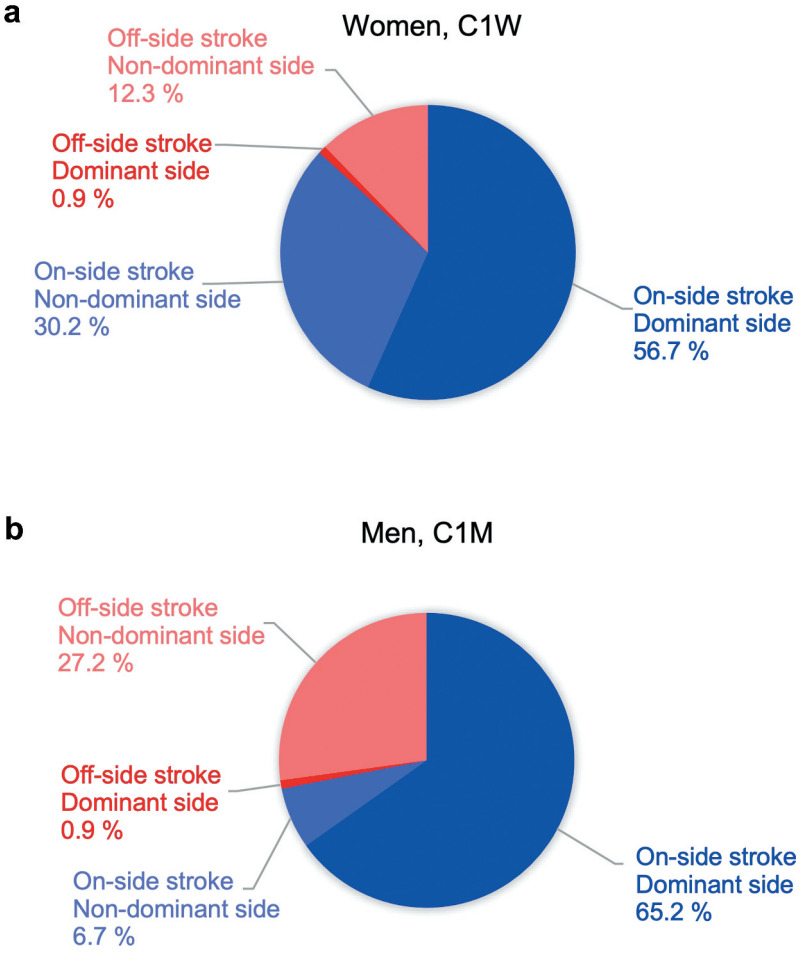

Figure 3. The proportions of different stroke types used in C1 slalom races. On-side strokes are shown in blue, off-side strokes in red. Dominant and non-dominant strokes are shown by lighter and darker colours, respectively. Data are shown for female C1W athletes (a) and male C1M athletes (b).

Table 2. Proportion of different types of paddle stroke (%) and least-square means for the main effects of sex and stroke type on the drive durations (s) and stroke durations (s).

	C1W			C1M		
Stroke Type	Proportion	Drive duration	Stroke duration	Proportion	Drive duration	Stroke duration
	(%)	(s)	(s)	(%)	(s)	(s)
On-side dominant	56.7	0.60	1.13	65.2	0.52	0.99
Off-side dominant	0.9	0.72	1.24	0.9	0.47	0.94
On-side non- dominant	30.2	0.63	1.15	6.7	0.53	1.01
Off-side non-dominant	12.2	0.64	1.19	27.2	0.56	1.02

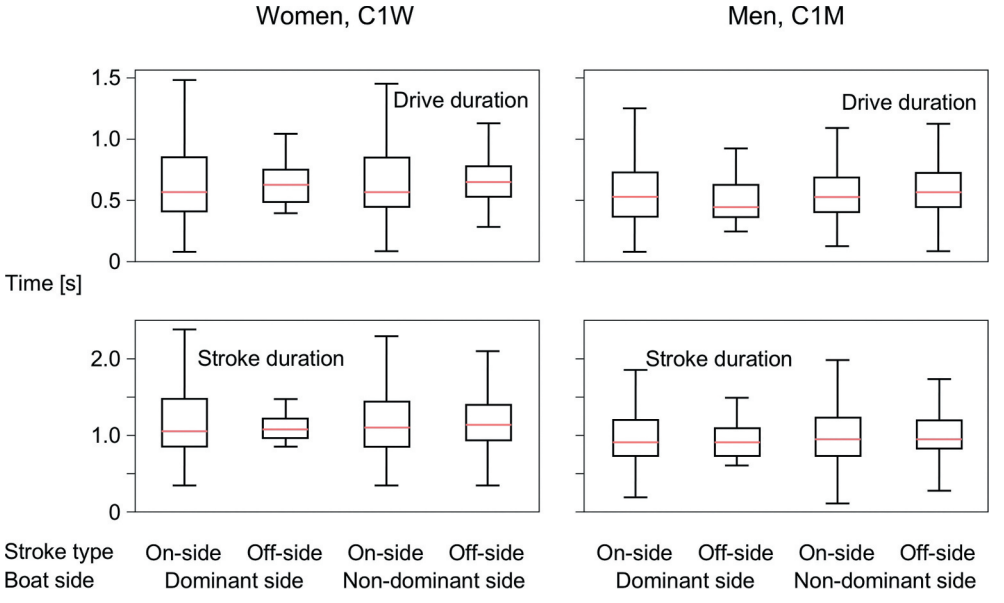

Figure 4. Drive and stroke durations for the different types of paddle stroke. Box plots show the median (orange bar), interquartile range (box), 5th percentile (bottom whisker), and 95th percentile (top whisker). Data are distinguished by female C1W athletes and male C1M athletes.

Table 2). This result indicated that the C1W athletes paddled with a lower stroke frequency. The main effect for stroke type showed that there was no significant difference between the drive (0.59 s) durations of off-side strokes and on-side strokes (0.57 s, Table 2).

C1W athletes performed a significantly greater proportion of switch and on-on transitions than C1M athletes. In contrast, C1M athletes performed a significantly greater proportion of cross and off-off transitions than C1W athletes (Table 3).

Different types of transitions had significantly different durations (Figure 5, Table 3). The interaction effects showed that there was no significant difference between On-on and Off-off transitions and between C1W and C1M, and these were the quickest type of transition (Figure 5, Table 3). The switching transition was the slowest type of transition and was not significantly different between C1W and C1M (Figure 5, Table 3). The cross transition occurred with an intermediate speed: the cross transition was significantly

Table 3. Least-square means for the main effects of sex and transition type on the transition duration between strokes. Common letters denote transition types that are not statistically different from each other, asterisks denote a significant interaction of sex and transition type.

	C1W		C1M			
Transition type	Proportion (%)	Transition Duration (s)	Proportion (%)	Transition Duration (s)	Main effect of transition duration	Interaction of transition duration*sex
On-on	73.5	0.45	58.1	0.44	A	
Off-off	5.9	0.44	15.4	0.42	A	
Cross	13.5	0.56	25.1	0.48	B	*
Switch	7.2	0.89	1.5	0.71	C	

slower for C1W than for C1M, but the time for the cross transition for C1M was not significantly different from that for the On-on or Off-off transitions (Figure 5, Table 3).

Discussion and implications

Our study aimed to quantify the difference in paddling technique that exists between C1M and C1W slalom athletes. The results supported our first hypothesis that C1W athletes perform a greater proportion of switch transitions than C1M athletes in international slalom competitions (Table 3), verifying what is considered common knowledge among canoe slalom athletes and coaches. Sporting technique evolves over time, and the current trend in canoe slalom is that more C1W use the switching technique. These results provide an evidence-based perspective on current technique by which future studies can be compared.

We can speculate on the possible reasons behind the popularity of this technique among C1W slalom athletes, but further research is required to support these ideas. Many C1W athletes started their sport careers as kayakers, possibly because K1W debuted as a demonstration event in the 1972 Olympics, whereas C1W slalom is only entering the Olympics for Tokyo 2020. Female C1W athletes, who started as kayakers, likely feel more comfortable paddling on both sides of the boat compared to an athlete who has exclusively canoed.

Diafas et al. (2010) found that slalom paddlers have higher rates of injury than recreational paddlers, and that injury rates increase with the amount of days paddled each year and years paddled overall (Diafas et al., 2010). In particular, 30% of canoeists reported chronic forearm and elbow injuries (Diafas et al., 2010). These findings suggest that elite canoe slalom athletes are at greater risk of developing chronic overuse injuries, such as tendinitis or sprains/strains, due to the nature of their sport and the frequency of training required to reach an elite level. The switching technique allows for a more balanced training across the body and minimises repetitive unilateral muscle contractions and joint movements (Busta, 2020). In addition, athletes likely minimise muscular fatigue by switching their grip on the paddle. An athlete may also switch to enhance stability or efficiency for challenging moves (Busta, 2020). Switching allows the athlete to transition to their non-dominant side while still paddling with on-side strokes (Figure 1). This corresponds to the greater proportion of on-side strokes and non-dominant side strokes observed in C1W athletes (Figure 3). Indeed, Hunter et al. (2008) found that male C1M athletes perform significantly more bracing (supporting) strokes on their on-side,

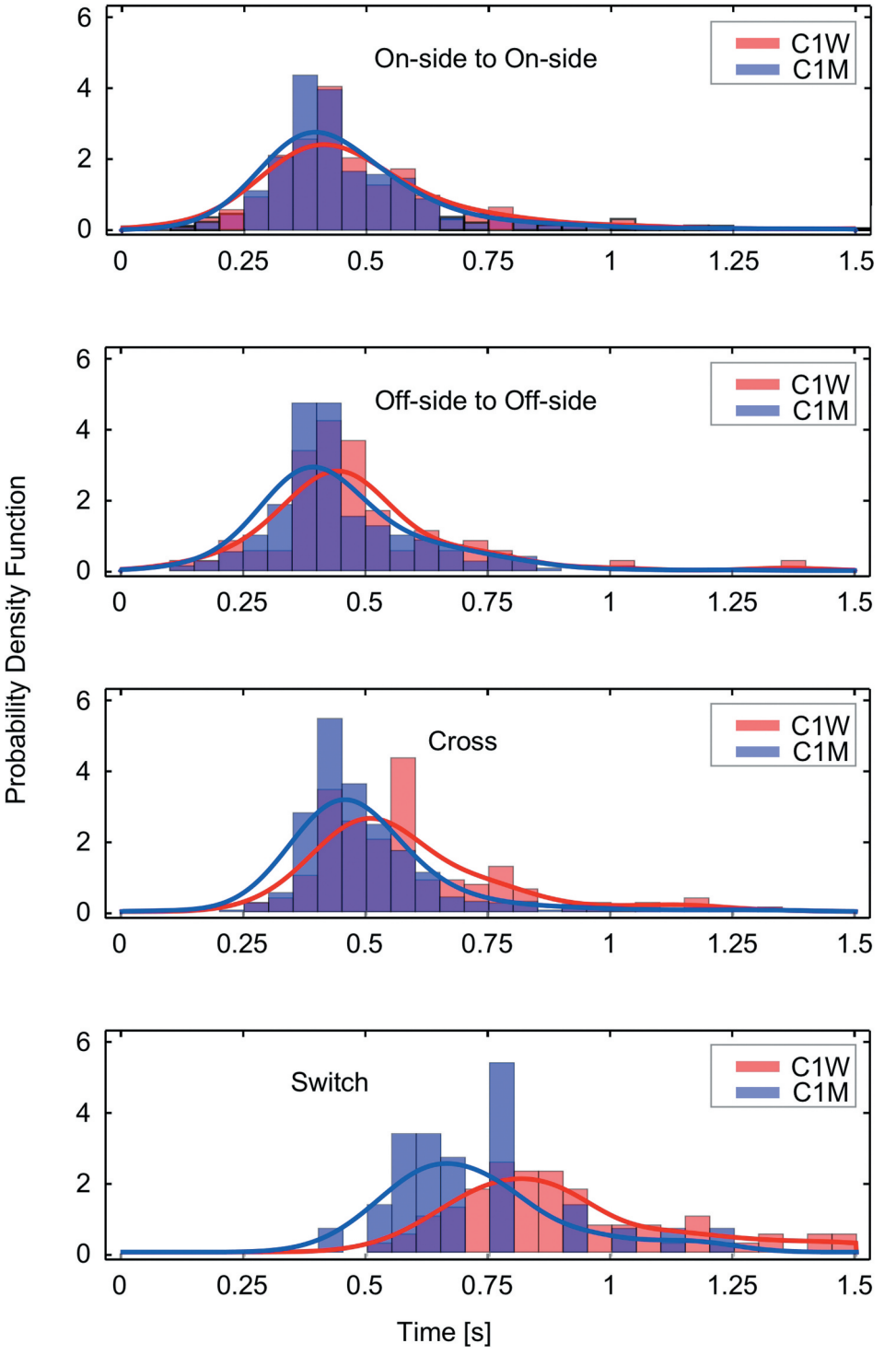

Figure 5. Probability density functions for the transition times between different stroke types. Data are distinguished by female C1W athletes (red) and male C1M athletes (blue).

suggesting that athletes may be more practiced, or feel more confident, navigating challenging sections of the course on their on-side.

Despite the potential benefits of the switching technique, we found that switching is slower than crossing and this is probably because the athletes need to change their grip on the paddle shaft to switch. The athlete and boat slow down during the stroke transitions from the restive drag forces between the boat and water but cannot generate propulsive forces between the blade and water during the transition. Switch transitions require additional time compared to the cross transition and this may detract from the net propulsive force and thus velocity of the boat. Consequently, repeated switching could contribute to a longer race time and this is an avenue for future research. However, if an athlete switches to make use of stronger strokes, be more stable or delay fatigue, then this may compensate for the slower transition time.

Despite the popularity of switching transitions among female athletes, it is still uncommon to find male athletes who use the switching technique in 2020 in international competition. We had to expand our inclusion criteria to find just four male athletes who switch. According to this trend, it is not surprising that male athletes performed a greater proportion of cross transitions than female athletes. Athletes who use the cross transitions must paddle on their non-dominant side with an off-side stroke (Figure 1). This corresponds to the greater proportion of off-side strokes observed among male athletes (Figure 3). Although male athletes don't switch as often as females, it is interesting to note that the time for the switching transition was not significantly different between female and male athletes. By contrast, female athletes were significantly slower at cross transitions compared to the male athletes. In our study sample, 7 out of the 11 male athletes exclusively used cross transitions, but only 2 of the 8 females exclusively crossed, while the rest of the athletes used a combination of crossing and switching. Male athletes may be faster at cross transitions because they are more practiced from exclusively crossing, compared to the females who combine switching and crossing, and are therefore less practiced at either technique.

Male athletes may prefer to cross, rather than switch, because it is the traditional technique used in the sport and their muscles have adapted to paddle this way. The male athletes we analysed were, on average, both older and more experienced than the female athletes (average of 16.5 and 9.2 years of international C1 competition experience, respectively). The C1M group included older athletes than the C1W because C1M has been an Olympic and World Championship event for longer than C1W and therefore the most competitive international C1M athletes tend to be older and more experienced than the top C1W. Bílý and co-workers (2013) found male slalom canoeists had a greater muscle mass (measured by fluid distribution) in the bottom arm that holds the paddle shaft, than in the top arm that holds the T-grip, due to the asymmetric nature of the canoe paddle stroke. Athletes who prefer the cross technique may be capitalising on their increased muscle mass in the bottom arm to apply greater paddle force on both sides of the canoe, thus increasing their power output. In addition, muscle memory from years of exclusively crossing may make the learning of a new skill such as switching more challenging mid-way through a competitive career. However, with the emergent popularity of switching, these trends may change as coaches are encouraged to include switching in the initial training of all young athletes (Busta, 2020). Interestingly, 2 of

the 4 male athletes who switched were the youngest and least experienced male athletes in our sample.

Overall, C1W athletes had a reduced stroke frequency compared to C1M athletes. In general, male athletes have greater force output during upper-body exercises compared to female athletes due to their higher percentage of muscle mass in the upper body (Sandbakk et al., 2018). Female C1W athletes may partly compensate for their reduced upper-body muscle mass and force output by increasing the proportion of the stroke used for the drive duration (propulsive phase): this will increase the relative propulsive impulse compared to the resistive forces that occur throughout the stroke. Similarly, Macdermid et al. (2019) found that a longer stroke duration was significantly correlated to greater impulse in elite kayak slalom athletes under flatwater simulated race conditions.

The results did not support our second hypothesis in that we found no significant difference in drive durations between off-side and on-side strokes. When evaluating the stokes for C1M athletes, the off-side drive durations were slightly longer than the on-side strokes (Table 2) similar to Hunter et al. (2008) study; however, these differences were not significant in our study.

We found that C1M athletes perform a significantly greater proportion of dominant side strokes compared to C1W athletes (Figure 3). This relates to the finding that most male athletes exclusively use the cross transition, and therefore, every non-dominant side stroke must be an off-side stroke. We speculate that on-side strokes are more powerful than off-side strokes and this could be why male athletes choose to favour on-side strokes on the dominant side and use the non-dominant side more sparingly. This finding agrees with previous reports that C1M athletes perform off-side strokes at a lower frequency than on-side strokes (Hunter et al., 2008).

Our study had several methodological limitations. We analysed all visible strokes in the race videos, including both forward and turning strokes. Most strokes in a C1 competition are forward strokes, however, the different types of stroke have different stroke durations (Hunter et al., 2008). Additionally, we analysed competition runs from a series of courses that were different between the C1W and C1M competitions: each time a course is set it will demand a different strategy and set of strokes from each athlete. However, despite the range of courses and stroke types that we analysed; a major finding was that even the quickest switching transition identified took longer than the median time for any of the other transitions (Figure 5). Additionally, publicly available race footage involved single cameras filming large sections of the course. The camera view was not always optimal to clearly identify the features of the paddle stroke. Multiple camera views, as are currently available to the competition penalty judges, would assist with stroke technique analysis. Lastly, C1 athletes sometimes perform blended strokes that seamlessly transition from one stroke to the next. Instrumented paddles, or motion sensors on the boat would help identify when the paddle provides propulsive force in the drive phase or when it was being transitioned to the next stroke.

This study provides essential fundamental knowledge regarding differences in stroke technique between C1M and C1W canoe slalom athletes. Quantification of technique differences is valuable to understand where each sex gains or loses time and how this contributes to performance in competitions. These findings will benefit athletes, coaches and sport scientists by informing future athlete training and research.

Acknowledgments

We thank Benjamin Ghertner for his help in data analysis, and Stanislava Smiešková for her insight and expertise in canoe slalom technique.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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