Canoe Slalom Competition Analysis

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Abstract

The purpose of this study was to quantify the differences between groups of elite canoe slalom athletes based on the class they paddle in and strategies they use in competition. Canoe and kayak footage was recorded using three cameras and analysed using lapsed-time time-motion analysis. Analysis was undertaken on the ten fastest competition runs for men's kayak and canoes and women's kayak for the twenty-two gate semi-final/final course at the 2005 canoe slalom world championships. Comparison between the categories of paddlers revealed that despite canoe paddlers taking significantly ($p \leq 0.05$) fewer strokes than kayak paddlers they were not significantly slower than men's single kayak paddlers with respect to their run times and only significantly slower between four out of twenty-two gates. Results revealed also that paddlers using different turn strategies (spin vs. pivot) had significantly ($p \leq 0.05$) different split times for the gates before and after the execution of the manoeuvre. For a paddler this means that their individual strategy could be analysed and compared to others to determine if alternate strategies would be beneficial to their performance.

Introduction

Most major international and national sporting competitions and some local and youth competitions are televised as part of the entertainment industry. Krosshaug, *et al*. (2005) suggested that this represents a tremendous opportunity to collect video footage of sports injuries and analyse their mechanisms. Davies (2003) recognized that quick, accurate and measurable performance analysis from video could be used for player selection, talent identification, player development and instant competition feedback and analysis. Many team sports already use event coding systems to provide detailed individual, unit and team analysis, as well as detecting strengths and weaknesses of opponents (Lyons, 2002). Therefore, many sporting events which are not televised are often recorded on video by athletes, coaches and sports scientists for qualitative and quantitative feedback. For sports scientists this represents an opportunity to collect competition specific information which can be used for research purposes.

Time-motion analysis has been used to assess the physical and physiological demands of sport and involves recording the modes of motion used throughout the performance. The use of computer-based time-motion analysis has expanded the analytical procedures that are possible and enabled more sport specific information to be measured (Bloomfield, *et al*., 2005). In sports such as football (McKenna *et al*., 1988) and squash (Flynn, 1998) time-motion analysis has been used to identify the relationship between performance and particular skills, methods of locomotion and sections of the game/competition. Time-motion analysis has also been used to answer specific research questions such as the relationship between unforced errors and the outcome of a squash game (Flynn, 1998). Spencer, *et al*., (2004) utilised time-motion analysis to characterise changes in movement patterns with specific attention to repeated-sprint ability of elite male field-hockey players during an international game. Application of this type of research to canoe slalom could lead to the identification of variables relating to performance.

It has been reported that the main advantage of the time-motion analysis is that it offers a non-intrusive method of analysing performance during competition (Bloomfield, *et al*., 2005). Therefore, in sports where limited information exists about the movement patterns time-motion analysis can be used to document these without interfering with the competition. An example of this is the documentation of the movement patterns and repeated-sprint activity during an international field hockey game completed by Spencer, *et al*. (2004).

Large discrepancies have been reported in the distances covered by football players due to methodological differences of time-motion analysis studies (Bloomfield, *et al*., 2005). Therefore, before beneficial comparisons can be made using time-motion analysis, standardised operational definitions identifying the skills, methods and sections of the sport need to be developed (Pearce, 2005). Hunter, *et al*. (2007) developed definitions which covered all performance variables obtainable from video footage of canoe slalom competition. These included the time taken between gates (gate split times), touched and missed gates, specific split times around upstream gates (turn times), major and minor avoidance, any instances where the boat capsized (rolls) and the time when the paddle entered and exited the water (paddle in and out times) as well as stroke categorisation.

In addition to standardised methods and definitions, researchers must consider the reliability of the results gathered using time-motion analysis. Hunter, et al. (2007) assessed the definition set developed for canoe slalom with respect to the measurement error and reliability for both single and multiple observers. The confidence limit for time taken between gates and turn times was ≤±0.23 seconds. The confidence limit for stroke in and out of water times was ≤±0.07 seconds. Inter-observer analysis revealed identical stroke identification was achieved 81% of the time. Results of this investigation revealed that a single observer was more reliable, but both single and multi observer analysis was comparable to previous time-motion analysis reliability studies on gait and association football.

Currently there is a paucity of information on the effectiveness of strategies which different canoe slalom categories employ to negotiate the same course. Although differences in boat and paddle design between kayaks and canoes may influence the extent to which strategies can be transferred between the categories, a better understanding of performance can be developed by comparing where each category gains or loses time relative to one another. This would allow paddlers to optimise the strategies they employ not based solely on the best in their own category but the best at each section of the course in any category. This study aimed to quantify the differences between groups of elite canoe slalom athletes based on the class in which they paddle and the strategies they use in competition.

Methods

Elite canoe slalom coaches worked with the researchers to develop a definition set that covered performance variables obtainable from video footage of canoe slalom competition. The resultant definition set could be used for men's kayak, women's kayak (paddle with two blades) and men's single canoe (single bladed paddle) and included the following measures: gate split times (time taken between gates), touched and missed gates, turn times, major and minor avoidance (contortion of body around a gate), rolls, paddle in and out of water times, and stroke categorisation. Strokes were recorded as being on the left or right hand side of the boat from the paddler's perspective for all categories. However, for the canoe category, the preferred side was also noted so that left and right could be changed to on-side (preferred) and off-side (non-preferred) strokes post analysis. Strokes were defined as the time period between the paddle in and the paddle out point and these were broken down into two categories, pure (single phase) strokes and multi (dual phase) strokes.

Pure strokes were identified as strokes that have one predominant phase and included the following strokes: forward, C, draw, sweep, reverse sweep, reverse, tap, brace, punt, side draw and steering. However, many strokes taken during a slalom competition are a mixture of different types of strokes.

Therefore, strokes that fell into more than one category but were not multi-strokes were defined by what the predominant action of that stroke was.

Multi-strokes were identified as strokes where the paddler did not remove their blade from the water before performing a second type of stroke. In some situations the paddler sliced the blade through the water to get to the starting position of the next stroke, whereas in others the starting position of the second stroke was the end of the first. However, the phases or sections of these multi-strokes are identifiable as separate types of strokes, but given one stroke count. For example, a stroke which consists of a draw followed by a forward stroke, where the paddle did not leave the water, was defined as a 'draw-forward' and the stroke count for this was one. An exception to this was made for the men's canoe paddle stroke with each time pressure of the blade on the water was released it was counted as the end of a stroke. If the blade was moved to a new location without pressure on the blade and followed by re-applying of pressure, even if it did not leave the water, it was counted as a new stroke. This was a result of men's canoe natural inability to remove the paddle from the water during the recovery phase on their off-side strokes. The strokes that were included as multi-strokes were: draw-forward, reverse sweep-forward, forward-reverse sweep, draw-draw, reverse sweep-draw, draw-sweep, forward-sweep and major/minor strokes.

Hunter, *et al*. (2007) details these stroke characteristics and race definitions in greater detail including the name, a description of the main characteristics of the stroke, the effect the stroke had on the boat in long and short descriptions as well as a diagram of the stroke for each of the following types of strokes.

The definition of a turn for the purpose of this investigation defined as up to four split times recorded around an upstream gate depending on the camera angle and course design. Figure 1 illustrates the four times taken. Turn times one and four were defined as the point where the centre of the boat passed parallel to the gate line and two and three were defined as the point where the centre of the boat passed a line perpendicular to the gate line originating from the inside pole.

Thirty competition runs from the semi-finals and finals of the 2005 world championships were filmed using three Sony® digital video cameras (DSR-PDX10P PAL). Each of the three cameras was situated in the best position to view its respective section of the course, whilst overlapping with the other section. These cameras recorded onto Sony® digital video cassettes (DVM60) and were time stamped to an accuracy of 1/50th of a second. To aid analysis the paddler was continually framed using the zoom and pan so they filled the frame and the shutter speed for both cameras was set to faster than 1/1000th of a second. This footage was subsequently captured onto computer using video editing software capable of producing a sample rate of 25Hz.

The ten fastest runs from men's kayak, women's kayak and men's canoe were selected for analysis. Each trial was analysed by one of the three trained observers using a custom written computer program. This program was specifically written for the analysis of canoe slalom competitions to enable synchronisation of multiple videos so that timing for the entire run was continuous and temporal and stroke information could be extracted. One observer checked the data from each run following the analysis of the run to ensure that there were no analysis errors.

Gate split times, turn times, total stroke information, left and right stroke information and gate errors were extracted into separate tables so the following statistic analysis could be performed on the data. Two turning methods were identified for analysis including the spin, which was defined as when the paddler turns away from the next gate, turn angle is greater than 180 degrees and pivot, which was defined as when the paddler turns towards the next gate, turn angle, is less than 180 degrees were used to assess strategy. The strategy paddlers used between gates nine and fifteen were used to group paddlers into one of eight categories which included: Spin-Spin-Spin, Pivot-Pivot-Pivot, Pivot-Pivot-Spin, Spin-Spin-Pivot, Spin-Pivot-Pivot, Pivot-Spin-Spin, Spin-Pivot-Spin and Pivot-Spin-Pivot. For gates twelve and fifteen paddlers were grouped into four different strategies: Spin-Spin, Pivot-Spin, Spin-Pivot, Pivot-Pivot.

Descriptive statistics and a one-way ANOVA with a Scheffe post hoc test were used to analyse split times with respect to category and strategy, time spent in each quarter of an upstream gate with respect to category and the number of touches and major and minor avoidances with respect to category. To assess variance for split times over the course descriptive statistics and the coefficient of variation were used. Gate by gate analysis of strategy and comparison between Pearson's correlations for split time/run time and turn time/run time were assessed using a 2 tailed t-test in which equal variance was not assumed. Comparison of right and left sides in men's kayak / women's kayak and preferred (onside) and non-preferred (offside) for men's canoe with respect to stroke counts, stroke types and categories were assessed using descriptive statistics. To assess the relationship between stroke time / run time and stroke count / run time a Pearson's correlation was used. The significance level was set at $p<0.05$.

Results

Gate Split Times

Comparison between run times (cumulative time to gate twenty-two) of different categories revealed that the top ten paddlers in women's kayak were significantly ($p<0.05$) slower than the top ten in men's kayak and men's canoe, but men's kayak and men's canoe were not significantly different from each other. Normalising the mean women's kayak and men's canoe run times to the mean men's kayak run time revealed that women's kayak and men's canoe took 110.9% and 103.0% of the mean men's kayak time respectively. The top ten paddlers in each category were within ten seconds of each other, as a percentage of the fastest run time this represented an eight percent range (Table 1).

Table 1: Category comparison for Mean Run Times and Variation			
Category	**Mean Run Time ± SD (s)**	**Variation SD**	**Variation Range**
Women's Kayaks	108.48 ± 2.61 $_{ab}$	2.5%	6.4%
Men's kayaks	97.86 ± 1.34 $_{a}$	1.4%	4.0%
Men's Canoes	100.77 ± 2.17 $_{b}$	2.2%	7.8%

a = significant different exists between groups with matching letters (p<0.05)

i.e. – ab is significantly different to both a and b

Analysis of the split times achieved by each category revealed that men's canoe and men's kayak were evenly matched for the majority of gates. However, men's canoe were significantly slower than men's kayak for four gates out of twenty-two. Results also revealed that women's kayak were significantly slower than men's kayak and/or men's canoe for all but five gates out of twenty-two. Comparison of the standard deviation in split times across all categories revealed that there was a slight increase towards the end of the race. However, the coefficient of variation for split times did not show this trend. The greatest variation when both standard deviation and coefficient of variation were considered occurred on gates eleven and fourteen (Table 2).

Table 2: Category comparison for Mean Split Times

		Mean Split Times (seconds) ± Standard Deviation		
Gate	**Direction**	**Women's Kayaks**	**Men's kayaks**	**Men's Canoes**
1	DOWN	1.47 ± 0.18 $_{a}$	1.60 ± 0.21	1.70 ± 0.21 $_{a}$
2	DOWN	2.50 ± 0.47 $_{ab}$	2.03 ± 0.19 $_{a}$	2.12 ± 0.21 $_{b}$
3	DOWN	3.32 ± 0.29	3.43 ± 0.21	3.48 ± 0.17
4	UP	7.16 ± 0.46 $_{ab}$	6.36 ± 0.28 $_{a}$	6.52 ± 0.29 $_{b}$
5	DOWN	7.26 ± 0.28 $_{a}$	6.81 ± 0.37 $_{ab}$	7.34 ± 0.34 $_{b}$
6	DOWN	2.52 ± 0.23 $_{ab}$	2.24 ± 0.12 $_{a}$	2.13 ± 0.20 $_{b}$
7	DOWN	5.20 ± 0.21 $_{ab}$	4.72 ± 0.28 $_{a}$	4.90 ± 0.25 $_{b}$
8	UP	8.05 ± 0.84 $_{ab}$	6.88 ± 0.37 $_{a}$	6.95 ± 0.38 $_{b}$
9	UP	4.91 ± 0.54 $_{a}$	4.60 ± 0.35	4.35 ± 0.46 $_{a}$
10	DOWN	4.48 ± 0.67	4.45 ± 0.59	4.24 ± 0.35
11	DOWN	4.38 ± 0.92 $_{a}$	3.17 ± 0.68 $_{ab}$	4.00 ± 0.54 $_{b}$
12	DOWN	3.45 ± 0.13 $_{a}$	3.06 ± 0.18 $_{ab}$	3.32 ± 0.21 $_{b}$
13	DOWN	3.18 ± 0.25 $_{ab}$	2.90 ± 0.18 $_{a}$	2.86 ± 0.25 $_{b}$

14	DOWN	4.65 ± 1.02 a	3.78 ± 0.69 a	3.97 ± 0.81
15	DOWN	3.77 ± 0.53 ab	3.20 ± 0.51 a	3.33 ± 0.27 b
16	UP	7.06 ± 0.18 ab	6.44 ± 0.51 a	6.44 ± 0.29 b
17	DOWN	5.28 ± 0.28 ab	4.91 ± 0.50 a	4.85 ± 0.17 b
18	DOWN	6.64 ± 0.57 a	5.83 ± 0.26 ab	6.26 ± 0.25 b
19	DOWN	2.53 ± 0.22	2.33 ± 0.21	2.45 ± 0.26
20	UP	6.45 ± 0.96 a	5.78 ± 0.52	5.51 ± 0.40 a
21	UP	9.87 ± 0.53 a	9.16 ± 0.66 ab	10.18 ± 0.66 b
22	DOWN	4.36 ± 0.46 a	4.19 ± 0.33 b	3.86 ± 0.28 ab

a = significant different exists between groups with matching letters

i.e. – ab is significantly different to both a and b

Strategy

Between gates nine and fifteen, paddlers used six of the eight possible strategies. The strategies used were Spin-Spin-Spin, Pivot-Pivot-Pivot, Pivot-Pivot-Spin, Spin-Spin-Pivot, Spin-Pivot-Pivot and Spin-Pivot-Spin. Results revealed that 100% of men's kayak and women's kayak and 70% of men's canoe paddlers performed a spin to negotiate gate ten therefore, only the men's canoe category was analysed further. Analysis of the turn strategy used for gate ten revealed that the spin method was significantly faster (p=0.01) for the gate nine to gate ten split whereas the pivot was faster although not significantly (p=0.08) for the gate ten to gate eleven split. When the split between gates nine and eleven was considered there was no difference between the spin and pivot strategies (Table 3).

Table 3: Comparison between Strategies used by Men's Canoe Paddler's for Gate 10

Strategy	**n**	**Mean Split Times (seconds) ± Standard Deviation**		
		Gate 9-10	**Gate 10-11**	**Gate 9-11**
Spin at Gate 10	7	4.17 ± 0.42	4.36 ± 0.34	8.53 ± 0.40
Pivot at Gate 10	3	4.77 ± 0.18	3.97 ± 0.23	8.75 ± 0.16
P value		p = 0.01	p = 0.08	p = 0.26

For gates twelve to fifteen, paddlers were grouped into four different strategies dependent on what manoeuvre they did at gate thirteen and fourteen: Spin-Spin, Pivot-Spin, Spin-Pivot and Pivot-Pivot. Results revealed that for men's kayak and men's canoe Pivot-Pivot was significantly faster than Spin-Pivot (p=0.03) and faster but not significantly than Pivot-Spin (p=0.36) for the gate thirteen to fourteen split. However, for the gate fourteen to fifteen split use of the Spin-Pivot at gate thirteen and fourteen resulted in a significantly faster time than the Pivot-Spin (p=0.01) and a faster time (although not significantly) for the Pivot-Pivot (p=0.10). Only one men's canoe paddler performed a Spin-Spin so no comparison could be made.

Further to this, the strategy adopted at the gates thirteen and fourteen were analysed separately to assess their distinct effect or contribution to the split time between gates fourteen and fifteen. The analysis revealed that 50% of men's kayak and men's canoe paddlers (men's kayak 40% and men's canoe 60%) performed a spin to negotiate gate thirteen and 40% to negotiate gate fourteen. All of the women analysed performed a spin to negotiate gate fourteen therefore, they were removed from further analysis. More in depth analysis of the turn method used for gates thirteen and fourteen revealed that paddlers who used a spin strategy for gate thirteen were significantly faster (p=0.04) for the gate fourteen to gate fifteen split. However, those who performed a spin at gate fourteen were significantly slower (p=0.01) for the gate fourteen to gate fifteen split (Table 4). Interestingly, 40% of men's canoe, 70% of women's kayak and 90% of men's kayak paddlers performed a pivot at gate thirteen. Further more only one right handed men's canoe paddler performed a pivot (Table 4).

Table 4: Comparison between Strategies used by men's kayak and men's canoe Paddler's for Gate 13 and 14

Strategy	**n**	**Mean Split Times (seconds) ± Standard Deviation**		
		Gate 13-14	**Gate 14-15**	**Gate 13-15**
Spin at Gate 13	10	4.14 ± 0.77	3.08 ± 0.44	6.96 ± 0.73
Pivot at Gate 13	10	3.36 ± 0.62	3.45 ± 0.27	6.55 ± 0.62
P value		p = 0.11	p = 0.04	p = 0.20
Spin at Gate 14	8	4.00 ± 1.08	3.53 ± 0.27	7.53 ± 0.98
Pivot at Gate 14	12	3.79 ± 0.42	3.09 ± 0.39	6.88 ± 0.34
P value		p = 0.63	p = 0.01	p = 0.11

Turns

Comparison between each of the upstream gates analysed revealed that there were differences between the ratio of time spent in each quarter of the turn. These differences were represented in the standard deviation when all six gates were combined. Differences also existed between each category for the percentage of time spent in each section with the greatest difference existing between women's kayak and men's canoe. The mean for men's kayak was between that of women's kayak and men's canoe for each section when the data from all six gates were considered together. The percentage of time spent in each section of the gates when all six upstream gates were combined was significantly different. There appeared to be no relationship between the time taken from position one to position four and the percentage of time spent in each section. The time taken between position one and four was also no better than any other split at predicting overall performance (average r = 0.55 and 0.44 respectively). Analysis of the six upstream gates combined revealed that elite paddlers from all categories spent 16% ± 7% of their time in the first quarter, 36% ± 12% in the second quarter, 21% ± 7% in the third quarter and 27% ± 9% in the final quarter (Table 5 and Figure 1).

Table 5: Division of Time around an Upstream Gate

Section	Women's Kayaks	Men's kayaks	Men's Canoes	All
1 (1st quarter)	22% ± 7%	21% ± 6%	19% ± 7%	21% ± 7%
2 (2nd quarter)	39% ± 12%	36% ± 13%	33% ± 10%	36% ± 12%
3 (3rd quarter)	13% ± 6%	16% ± 7%	19% ± 8%	16% ± 7%
4 (4th quarter)	25% ± 10%	27% ± 10%	28% ± 8%	27% ± 10%

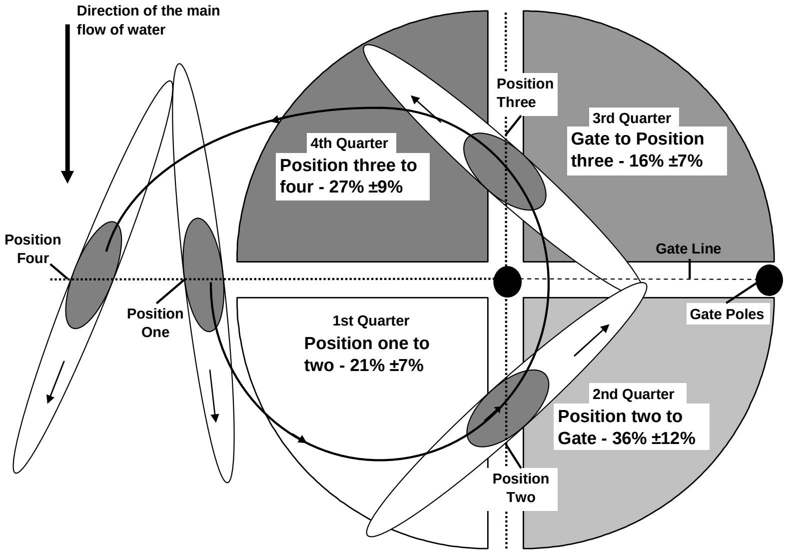

Figure 1: Division of time around an Upstream Gate

Strokes

Comparison of the total stroke count between classes revealed that women's kayak paddlers took an average of one hundred and eighteen strokes and men's kayak took one hundred and nine strokes. Men's canoe took eighty-four strokes and this was significantly less strokes than women's kayak and men's kayak paddlers. Further analysis revealed that forward strokes made up between 67% and 71% of strokes for all categories. Draw-forward was the next most commonly used stroke representing between 9% and 14% of the total number of strokes taken for all categories (Figure 2).

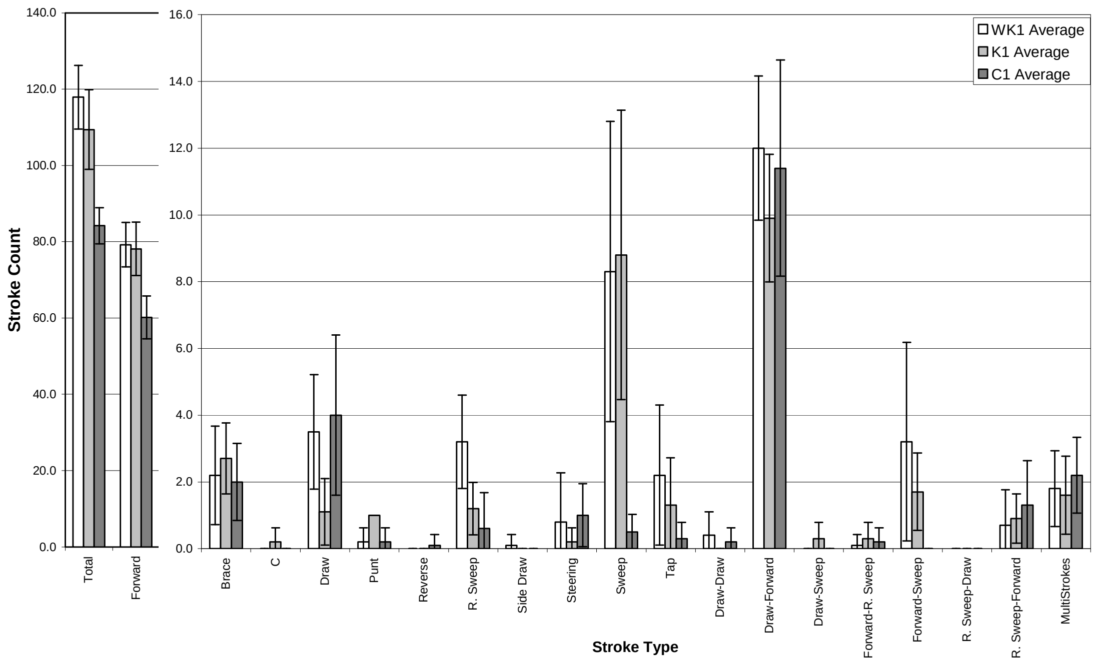

Figure 2: Total Stroke Count for each Category

Men’s canoe paddlers spent significantly longer with their paddle in the water than men’s kayak or women’s kayak paddlers when total strokes and forward strokes were considered. Draw-forward and multi strokes represented the longest strokes averaging around 1.5 seconds per stroke. The shortest strokes were taps with an average in water time of 0.12 seconds. On average the top ten paddlers spent 61% ± 2.7% of their time with the paddle in the water (Figure 3).

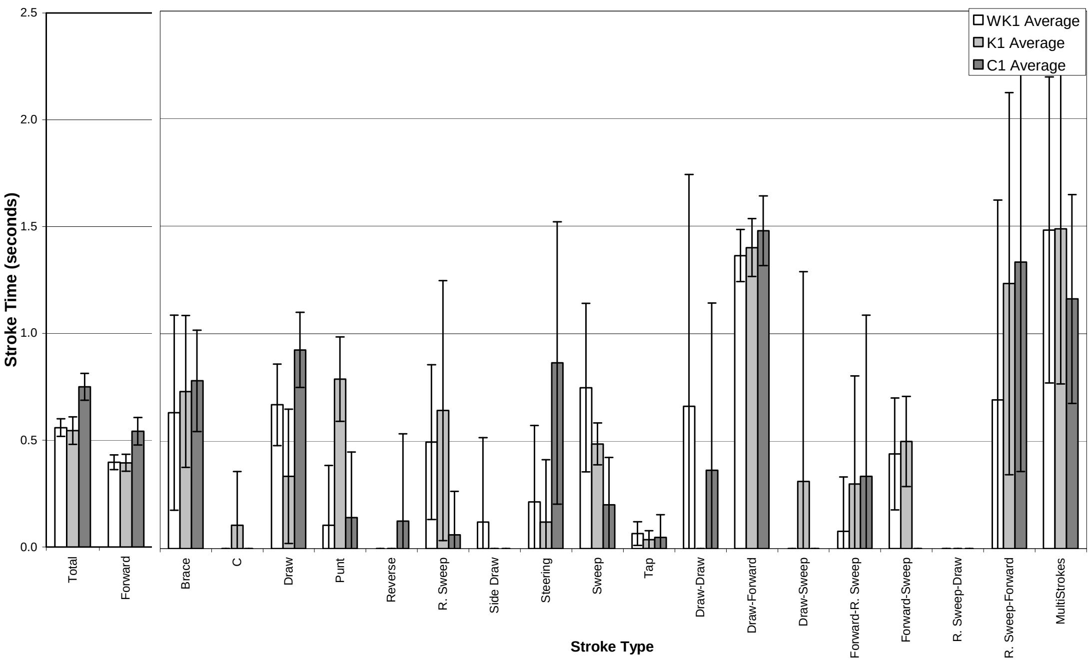

Figure 3: Average Stroke Time for each Category

A very-strong negative correlation (r=-0.89) was found between stroke count and stroke time over the length of the course. However, run time was found to be very-weakly correlated with stroke time (r=-0.14) and moderately correlated with stroke count (r=0.45). A positive correlation between time spent with the paddle in the water and run time existed (r=0.72). However, there was no relationship between the mean time spent with the paddle in the water per stroke as a percentage of run time and run time (r=-0.05) or run time normalise to the fastest paddler in each class (r=0.13).

When the strokes were separated into left and right for the kayak classes the differences in stroke count for each side was minimal. However, when men's canoe strokes were separated into onside and offside strokes there were significant differences between the sides. Men's canoe paddlers performed a similar number of strokes to kayak paddlers on their onside but on their offside men's canoe paddlers performed significantly fewer strokes ($p<0.01$). This was particularly observable in their total and forward stroke counts (Figure 4).

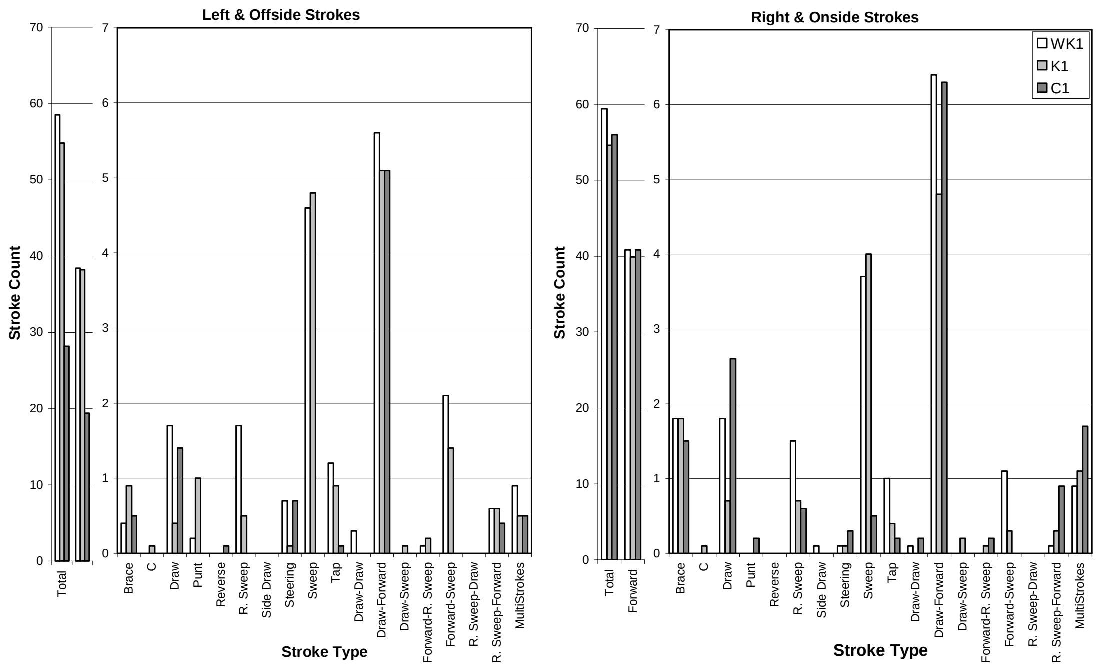

Figure 4: Left and Right Stroke Count for each Category

The left and right stroke time comparison revealed that men's canoe spent significantly longer with the paddle in the water on their offside compared to their onside. This was true for total, brace, draw, forward and sweep strokes ($p<0.05$). Interestingly, both men's kayak and women's kayak recorded significantly more supporting strokes (braces) on the right side (Figure 5).

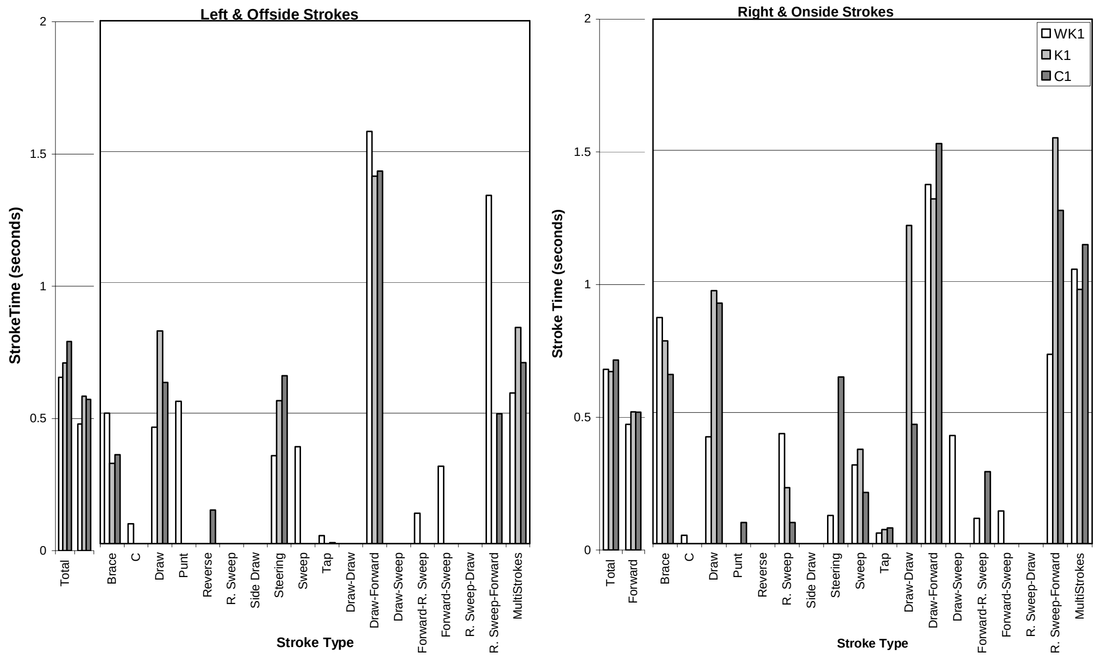

Figure 5: Left and Right Average Stroke Time for each Category

Penalties

The major finding relating to errors and avoidance around gates was that men's kayak paddlers recorded a significantly greater number of major avoidances than women's kayak or men's canoe. In addition, across all athletes only, six penalties out of a possible 660 were recorded which represented less than 1% of the total (Table 6).

Table 6: Mean number of Errors and Avoidance around Gates

Classes	Mean Number of Errors (Count) ± Standard Deviation		
	Women's Kayaks	**Men's kayaks**	**Men's Canoes**
2 Second Penalty	0.1 ± 0.32	0.2 ± 0.63	0.2 ± 0.42
Major Avoidance	0.9 ± 0.88	2.3 ± 1.89 *	0.4 ± .70
Minor Avoidance	0.9 ± 1.29	0.6 ± 0.70	0.9 ± 1.20
Avoidance (both)	1.8 ± 2.04	2.9 ± 2.02	1.3 ± 1.25

* significant at 0.05 level

Discussion and Implications

This study aimed to quantify the differences between groups of elite canoe slalom athletes based on the class they paddle in and strategies they use in competition.

Gate Split Times

The difference between the top ten women's kayak, men's kayak and men's canoe paddlers with respect to their run time indicated that males have an advantage over women in slalom kayaking. Comparison between the categories with respect to the range of times achieved by the top ten paddlers compared to the fastest paddler revealed that the variation in time was not significantly different. This suggested that the ability of the athletes within the top ten in each category was similar. Therefore, if the top ten in each category have similar technical abilities then the most likely cause of the slower run times in women's kayak would be strength differences. However, the technical ability of a paddler may be influenced by their strength, for instance they may not be able to perform certain manoeuvres which require a large physical input. The run times of men's kayak and men's canoe were not significantly different which indicated that men's canoe were not limited by only having one blade for the majority of the course. This suggests that men's canoe paddlers use their strokes more effectively than kayak paddlers. Therefore, kayak paddlers should consider incorporating strategies utilised by men's canoe into their own strategy to achieve greater efficiency. However, there were a few instances where they were unable to perform as well as both the kayak classes could. It should be noted that differences in boat and paddle design between kayaks and canoes may influence the extent to which strategies can be transferred between the categories.

Further analysis of the variation in split times across the race revealed that the variation in split times towards the end of the race within the top ten paddlers did not increase. This would indicate that either the top ten did not fatigue, fatigued at the same rate or that other variables such as technical ability caused greater variation in performance than fatigue did. Interestingly, gates eleven and fourteen which produced the greatest variation in split times were part of a complex section of the course where paddlers used numerous different strategies to negotiate the gates. This indicated that the technical component was actually a critical factor in slalom canoeing. That is, the technical sections caused the greatest differences between paddlers even within the top ten. This finding suggests that for paddlers to achieve the largest performance improvements they should focus on improving the skills and physical capabilities required to negotiate the technical sections of a course. This suggests also that in intense training contexts athletes should spend the majority of their time on technical rapids and gate sequences.

Strategy

In the top ten paddlers from each category there was a large amount of variation in strategy used for gates nine to fifteen with paddlers using six of the eight possible strategies. This probably resulted from the variation between paddlers with respect to training, equipment, technical ability, strength, decision-making skills and perception of the course. Interestingly, for gates ten to eleven a spin was performed by 90% of paddlers as opposed to the pivot. The spin proved faster between gates nine and ten. However, this was then reversed for the split between gates ten and eleven indicating that each strategy had its own benefits and drawbacks which ultimately resulted in a similar time being achieved between gates nine and eleven. That is, the pivot required the paddlers to take a wider line between gates nine and ten to clear gate ten without penalty but the faster turn resulted in a better line between gates ten and eleven. Whereas the pivot was more direct between nine and ten but the slower turn caused the paddler to be pushed off line and work more against the flow between gates ten and eleven.

For gates twelve to fifteen the number of possible strategies was reduced but, paddlers still used all four possibilities to negotiate the section of the course. Results revealed that for men's kayak and men's canoe there were detectable differences between the strategies. To gain further insight this section was broken down further into individual strategic movements revealing that those paddlers who performed a spin at gate thirteen were faster for gates fourteen to fifteen split times than those who performed a pivot. This time advantage was irrespective of whether they performed a pivot or a spin at gate fourteen. However those paddlers who performed a spin at gate fourteen were significantly slower for gates fourteen to fifteen split times than those who performed a pivot irrespective of the strategy they employed for gate thirteen.

Theoretically the fastest strategy to employ between gates fourteen and fifteen based on these results should have been a Spin-Pivot. However, results showed that Spin-Pivot was significantly slower than Pivot-Pivot for the gate thirteen to fourteen split. Therefore, when considering the strategy used between gates twelve and fifteen neither strategy was significantly better or quicker than the other. This was interesting because it demonstrated that strategies not only have an immediate effect but also can cause a delayed or carry on effect. In this instance, the most probable explanation was that paddlers who chose to perform a spin at gate thirteen were able to set up the turn at gate fourteen earlier and without decrement to speed and therefore had a better line to gate fifteen. However, those paddlers who chose to perform a spin at gate fourteen may have been unable to maintain their speed through the eddy or the physical time taken to complete the turn was detrimental to the split to gate fifteen. However, it should be noted that a large number of factors influence split times for each paddler and further research would be required to determine the exact cause of these time differences. Interestingly, the large number of men's canoe paddlers performed a spin at gate thirteen which was probably due to the side they paddled on as no right handed paddlers chose to perform a pivot as this would have been on their offside. Furthermore, only one right-handed men's canoe paddler performed a pivot and the rest were left-handed paddlers which demonstrated that in men's canoe the strategy that paddlers adopted was highly dependent on whether they were right or left handed.

Turns

Analysis of the methods paddlers adopted to negotiate upstream gates revealed that paddlers spend different percentages of time in each section (quarter) of an upstream gate. Furthermore, due to differences in gate location relative to the course and the erratic nature of the water, no upstream gates resulted in the same percentages of time being spent in each section which was represented by the standard deviation of each section. Interestingly, each of the categories also presented a different percentage of time spent in each section of an upstream gate indicating that each category had a unique way of approaching each upstream gate. The results revealed that men's kayak always represented the median of the three categories when all six upstream gates were combined, but this was not always true for each gate individually. It would be expected that there is an optimal ratio either side of which performance would be decremented. Interestingly, with the current elite group the majority of paddlers tended towards spending 16%, 36%, 21% and 27% in each quarter of the turn. This would suggest that time benefits could be most easily achieved through improvements in the second quarter of the turn (entrance to the gate) and the final quarter of the turn (exit / reacceleration from the gate). However, to analyse upstream gates more accurately further research would be necessary.

Strokes

Analysis of the number and type of strokes which the top ten paddlers in each category used revealed that of the 100 plus strokes used by men's kayak and women's kayak paddlers and 80+ strokes used by men's canoe paddlers, 67%-71% of the strokes were forward strokes. This indicates that the top paddlers are only trying to turn the boat on around 30% of strokes. Although the course will always require a minimum number of turning strokes to negotiate it without penalties, the closer to this minimum number of strokes a paddler can achieve the greater efficiency and speed they should also achieve. Further research could investigate this variable in relation to paddler skill level to determine if as the skill level decreases the percentage of forward strokes to turning strokes also decreases.

Results revealed that paddlers who take fewer strokes during the course achieve this by increasing the amount of time which they spend with the paddle in the water. However, as the total number of strokes for a run and mean stroke rate increases the mean time the paddler spends with the blade in the water (stroke time) decreases to approximately 0.5 seconds beyond which further decreases in mean stroke time become difficult. However, there was no observable relationship found between the number of strokes taken and the time achieved for the run. This probably results from the vast range of techniques and strategies by individuals to negotiate the same course.

Top paddlers spend on average 61% ± 1.0% of their total run time with the blade in the water. The total time that paddlers spent with their blade in the water during a run was found to be strongly correlated with their run time. This was expected as a longer run time would equate to a slower run hence the total time the paddle was in water would also be greater. However, this was not supported by the percentage of time the paddlers spent with the blade in the water, which indicated that there was no relationship to run time. That is, the percentage of time that the paddler spent with the blade in the water was unchanged irrespective of the how long the run took them.

Analysis of the number of strokes taken by each category revealed that men's canoe paddlers took significantly fewer strokes than men's kayak and women's kayak paddlers. However, it was found that this difference resulted from men's canoe paddlers taking fewer strokes on their off side. Comparison between the number of strokes men's canoe paddlers took on their onside and women's kayak and men's kayak paddlers revealed that they took a similar number of stokes. Further analysis revealed that men's canoe paddler spent significantly long with the blade in the water on their offside. Both the reduction in strokes and the increased time for each stroke probably resulted from the awkward nature of paddling on their offside. This reduction in strokes and increase in time in the water for men's canoe paddlers offside could indicate that men's canoe paddlers were matching the impulse they apply on their onside.

One interesting finding was that the number of supporting strokes (braces) recorded when comparing between sides revealed that paddlers tended towards one side more than the other. Men's canoe paddler recorded a significantly greater number of braces on their onside and both women's kayak and men's kayak paddlers recorded a significantly greater number of braces on their right hand side. In men's canoe this may have resulted from the natural dominance of one side compared to the other. However, in women's kayak and men's kayak the difference may have been an indication of underlying limb dominance or a result of the course design.

Penalties

Due to the low number of penalties in the top ten from each category it was difficult to determine if any relationships existed between penalties and performance. Major avoidance was the only variable in this area which recorded significant differences between the categories. Whether men's kayak paddlers take more risks to negotiate gates and make the top ten would require further research.

Conclusion

This study revealed that despite canoe paddlers taking significantly fewer strokes than kayak paddlers they were not significantly slower than men's single kayak paddlers with respect to their run times and only significantly slower between four out of twenty-two gates. In addition paddlers using different turn strategies (spin vs. pivot) had significantly different split times for the gates before and after the execution of the manoeuvre. For paddlers this means that their individual strategy could be analysed and compared to other paddlers to determine if alternate strategies would be beneficial to their performance.

Some specific research directions which have arisen through this investigation include: determining the factors which influence split times, more accurately assessing the techniques of elite performers around upstream gates, determining the relationship between a paddlers skill level and different variables and determining if certain groups of paddlers take a greater number of risks to negotiate gates. Also, further research into the effect of different courses on the performance of elite paddlers would be beneficial

References

Bloomfield, J., Jonsson, G.K., Polman, R., Houlahan, K., and O'Donoghue, P. (2005). In L. Anolli, S. Duncan Jr., M.S. Magnusson and G. Riva (Eds.). The Hidden Structure of Interaction: From Neurons to Culture Patterns (pp. 237-251). Amsterdam: IOS Press.

Davies, K. (2003). Utilising digital video for game, player, training and opposition analysis. *In, Conference program : International conference on the science and practice of rugby, Brisbane, Qld, The Conference, 2003,* 78.

Flynn, R. (1998). Are there statistically crucial tactical moments during squash matchplay? *Australian Squash Coach,* **Spring**, 18-21.

Hunter, A., Cochrane, J., and Sachlikidis, A. (2007). Canoe Slalom Competition Analysis Reliability. *International Journal of Sports Biomechanics,* **6(2),** 153-167.

Krosshaug, T., Andersen, T.E., Olsen, O-E.O., Myklebust, G., and Bahr, R. (2005). Research approaches to describe the mechanisms of injuries in sport: limit ations and possibilities. *British Journal of Sports Medicine,* **39**, 330-339.

Lyons, K. (2002). Performance analysis for coaches : an introduction. *Sports coach,* 25(3), 6-8.

McKenna, M.J., Patrick, J.D., Sandstrom, E.R. and Chennells, M.H.D. (1988). Computer-video analysis of activity patterns in Australian Rules Football. In T. Reilly, J. Clarey and A. Stribbe (Eds.). *Science and Football* (pp. 274-261). London: E. and FN Spoon.

Pearce, A. (2005). Video analysis: where do I start?. *Sports Coach,* **28(2)**, 34-36.

Schokman, P, Le Rossignol, PF, and Sparrow, WA. (2002). Validity and reliability of a voice-recognition game analysis system for field sports. *Journal of Science and Medicine in Sport,* **5(4)**, 362-371.

Spencer, M., Lawrence, S., Rechichi, C., Bishop, D., Dawson, B. and Goodman, C. (2004). Time-motion analysis of elite field-hockey, with special reference to repeated-sprint activity. *Journal of Sport Sciences.* 22: 843-850.