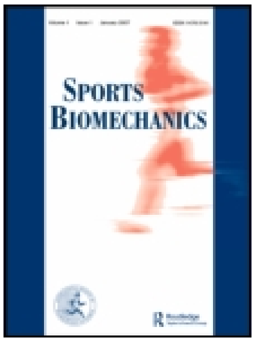


Sports Biomechanics

ISSN: 1476-3141 (Print) 1752-6116 (Online) Journal homepage: http://www.tandfonline.com/loi/rspb20

Canoe slalom – competition analysis reliability

Adam Hunter , Jodie Cochrane & Alexi Sachlikidis

To cite this article: Adam Hunter , Jodie Cochrane & Alexi Sachlikidis (2007) Canoe slalom – competition analysis reliability, Sports Biomechanics, 6:2, 155-170, DOI: 10.1080/14763140701324842

To link to this article: http://dx.doi.org/10.1080/14763140701324842

Sports Biomechanics
May 2007; 6(2): 155–170

Canoe slalom – competition analysis reliability

ADAM HUNTER[1,2], JODIE COCHRANE[1], & ALEXI SACHLIKIDIS[1]

[1]*Biomechanics Department, Australian Institute of Sport, Belconnen, ACT, and* [2]*University of Canberra, Canberra, ACT, Australia*

Abstract
The aim of this study was to assess intra-observer and inter-observer reliability of data gathered from a lapsed-time time–motion analysis of canoe slalom competition. The data were collected using a definition set developed in conjunction with elite canoe slalom coaches. Competition runs from four national-standard paddlers in a national selection race were analysed in random order three times by three observers. For each run, observers identified various events specific to canoe slalom, including time taken between gates, touched and missed gates, turn times, major and minor avoidance, rolls, paddle in and out of water times, and stroke classification. The error of measurement was determined for each of these variables. For time taken between gates and turn times, the error was ≤0.21 and ≤ 0.39 s for intra-observer and inter-observer analysis, respectively. The error for stroke in and out of water times was ≤ 0.08 and ≤ 0.13 s for intra-observer and inter-observer analysis, respectively. Analysis of stroke classification identification for intra-observer comparisons revealed that 91% of the time identical stroke identification occurred. Inter-observer analysis revealed identical stroke identification was achieved 81% of the time. These reliability data compare favourably with previous time–motion analysis in other sports using fewer variables.

Keywords: *Biomechanics, intra-observer reliability, inter-observer reliability, kayak, performance analysis, stroke*

Introduction

The need for quick, accurate, and measurable performance analysis has become an increasingly important aspect of elite sport (Davies, 2003). Event coding systems are used by many team sports to provide detailed individual, unit, and team analysis, as well as detecting opponents' strengths and weaknesses (Lyons, 2002). Time–motion analysis has also been used to answer specific research questions, including the determination of the relationship between variables such as unforced errors, and the outcome of a squash game (Flynn, 1998). This type of research has yet to be applied to the sport of canoe slalom; however, it is thought that its implementation would lead to the identification of important performance variables and indicators in canoe slalom competition (Hughes and Bartlett, 2002).

Time–motion analysis has been undertaken in sport to identify the use of particular skills, methods of locomotion, and phases of play in the game or competition that are related to

---

Correspondence: A. Hunter, Biomechanics Department, Australian Institute of Sport, PO Box 176, Belconnen, ACT 2616, Australia. E-mail: adam.hunter@ausport.gov.au

ISSN 1476-3141 print/ISSN 1752-6116 online
DOI: 10.1080/14763140701324842

performance, in sports such as association football (McKenna, Patrick, Sandstrom, and Chennells, 1988) and squash (Flynn, 1998). However, with any new application of time–motion analysis to a sport, a set of standardized operational definitions that identify skills, methods of locomotion, and phases of play needs to be developed (Pearce, 2005). This definition set enables any investigator to apply the method and produce comparable results.

Accurate and reliable performance data are considered to be a critical requirement for effective coaching. Quantitative analysis with proven and adequately reported reliability and validity should supplement subjective judgements of performance (Schokman, Le Rossignol, and Sparrow, 2002). However, Hughes, Cooper, and Nevill (2002) found that 70% of notational analysis papers did not report the reliability of any variables and that, in these papers, a large proportion of statistics were derived using questionable processes. For canoe slalom to gain valuable information from time–motion analysis, the definition set and the methods for data collection need to be assessed for reliability and validity.

Some studies, however, have assessed reliability measures, with reliability correlations $>$ 0.8. Schokman et al. (2002) assessed intra-observer and inter-observer reliability using voice recognition analysis to classify accurately gait transitions and to quantify gait durations from video. Both reliability measures were consistently high, ranging from $r = 0.87$ to $r = 0.99$. McKenna et al. (1988) reported that an acceptable reliability for a single observer recording the time a player spent performing gait- and game-specific activities was $r \geq 0.92$ for total time and $r \geq 0.83$ for a count of the activities.

The aim of this study was to determine the intra-observer and inter-observer reliability for time–motion analysis of canoe slalom competition using a specific definition set. The dependent variables used to assess reliability in this research were related to the time at which each event occurred in addition to the classification of each of these events.

Methods

Definitions

Australian Institute of Sport slalom coaches worked with the researchers to develop a definition set that covered performance variables obtainable from video footage of canoe slalom competition. This included gate split-times (time taken between gates), touched and missed gates, turn times, major and minor avoidance, rolls, paddle in and out of water times, and stroke categorization. These measures were developed for use in the analysis of the following boat categories: men's kayak (K1), women's kayak (K1W), and men's single canoe (C1). For the kayak categories, the strokes were recorded as being on the left- or right-hand side of the boat from the kayak paddler's perspective. For the canoe category, the preferred side was also noted so that left and right could be changed to on-side and off-side strokes in post-analysis. These stroke characteristics and race definitions are detailed in Table I. From these data, a comparison of the speeds of the boat during different sections of the race can be made, together with the number of errors made, the magnitude of these errors, and the impact on other aspects of the run. Strokes were defined as the period between the paddle-in and the paddle-out points and these were broken down into two categories, pure (single phase) strokes (Table II) and multi (dual phase) strokes (Table III). For each stroke, we provided the name of the stroke, a description of the main characteristics of the stroke, the effect the stroke had on the boat in long and short descriptions, and a diagram of the stroke. At the end of Table III, a key is provided that explains the stroke diagrams in Tables II and III.

Pure strokes were defined as strokes that have one predominant phase and included the following strokes: forward, C, draw, sweep, reverse sweep, reverse, tap, brace, punt, side

Table I. Stroke characteristics and race definitions.

Stroke characteristic	Description	Quick reference
Gate split times	- Look at lower torso in the spray deck if an accurate split can be attained from the poles of the gate - Front view: use a wave that can be identified in every run and then use when the nose or certain section of the boat breaks through the wave. This should be more consistent than trying to pick the gate	- To get consistent timing: 1. Use lower torso against poles or 2. Boat relative to waves
Touched gates	- Any part of paddle, paddler or boat makes contact with either pole - 2 second penalty	- Gate pole was hit - 2 second penalty
Missed gates	- The head of the paddler didn't go between the poles of the gate - 50 second penalty	- Gate missed by paddler - 50 second penalty
Turn times	- Turn times can be defined as the time when the boat was 90° to the water flow and then continued to turn beyond this point - For example: Turning upstream for an upstream gate and then return to pointing downstream = 2 turning points, one before and one after the gate	- Boat turning upstream or downstream (major change in direction) - Point where the boat is 90° to the main water flow
Major avoidance	- This occurs when the paddler contorts their body to get around / through a gate and this contortion results in their normal paddling technique, balance and/or propulsion being negatively affected - Propulsion of the boat becomes reduced due to major avoidance - For example: Hesitation before taking the next stroke, cut a stroke short, using an ineffective stroke	- Causes a negative impact on propulsion, balance and/or stroke
Minor avoidance	- This occurs when the paddler contorts their body to get around / through a gate but this contortion does not result in their normal paddling technique being affected - Propulsion of the boat remains unaffected during minor avoidance	- Does not impact on propulsion, balance and/or stroke
Rolls	- When the boat goes upside down and the paddler has to perform a roll to right themselves - To indicate the start and end of the period during which the boat was inverted	- Boat upside-down
Paddle in time	- Closest point to where the paddle begins to grip the water - If most of the blade can be seen, then it isn't in the water yet - If between frames then pick the frame on the side of definitely gripping the water - First point the paddle causes an effect on the boat	- In side of gripping the water - First point the paddle causes an effect on the boat
Paddle out time	- Closest point to where the paddle begins to be no longer effective in the water	- In side of losing grip with the water

Table I – *continued*

Stroke characteristic	Description	Quick reference
	- If most of the blade can be seen, then it has already left the water	- Last point the paddle causes an effect on the boat
	- If between frames then pick the frame on the side of still gripping the water	
	- Last point the paddle causes an effect on the boat	
Stroke	- A stroke is the period between the ‘”paddle in time” and “paddle out time”	- Paddle into paddle out
	- Defined as meaningful use of the paddle	- Meaningful use of paddle
On side	- C1 paddling on their preferred side	- Preferred side
	- Top hand crosses over deck	- Top hand crossed over deck
	- If left hand is the bottom hand on the paddle then on side = left	
Off side	- C1 paddling on their non-preferred side	- Non-preferred side
	- Bottom hand crosses over deck	- Bottom hand crossed over deck
	- If left hand is the bottom hand on the paddle then off side = right	

Table II. Stroke definitions – pure strokes.

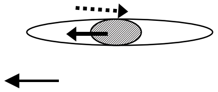
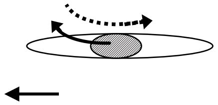
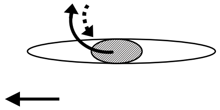
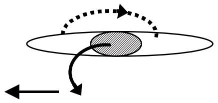
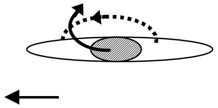
Stroke Name	Description	Effect on boat	Stroke effect	Stroke diagram
Forward	- Propulsive stroke - Normal paddle stroke (paddle pulls straight through water) - Top hand moves straight forward - Similar to old flat-water technique before blade changes	- Propulsion of the boat forward - Stern following bow - No significant change in direction - Boat tracks straight	Forward > 90%	
C	- Propulsive draw (smaller opening angle than draw) - One continuous action - Blade moves in a C-shaped path relative to the boat - Combines both actions together	- Turns boat while propelling it forward - Smooth movement in both turning and propulsion	Turn 50% Forward 50% or combination	
Draw	- Blade facing inwards, parallel to boat (more open) - Top hand kept high - Blade drawn in towards the bow of the boat	- Significant change in direction - Causes the boat to rotate (just turns the boat) - No real propulsion during stroke	Turn 100% Some forward run from previous strokes	
Sweep	- Blade moves in an arc around the paddler starting at the bow - Top hand moves low across body - Blade facing outwards	- Significant change in direction - Not much propulsion during stroke - Bow moves away from the blade	Turn > 90% Forward < 10%	
Reverse sweep	- Blade moves in an arc around the paddler starting at the stern - Top hand moves low across body - Blade facing outwards	- Significant change in direction - Does not slow the boat - Bow moves towards the blade	Turn > 90% Reverse < 10%	

Table II – *continued*

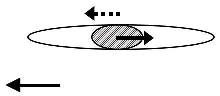
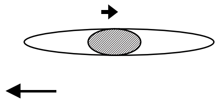
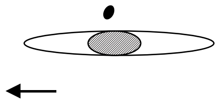
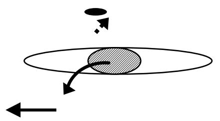
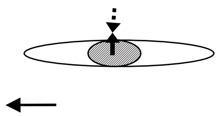
Stroke Name	Description	Effect on boat	Stroke effect	Stroke diagram
Reverse	- Braking stroke - Can propel boat backwards - Blade moves in a forward direction starting at stern - Often occurs behind the body	- Braking - Propulsion of the boat backwards - No significant change in direction	Braking $>$ 90% Turning $<$ 10%	
Tap	- Pure in and out of the water without much pressure on the blade - Very short stroke	- No observable effect on boat	Ineffective stroke Timing stroke	
Brace	- Face of blade facing the sky or river bed, shaft flat to water. - Supporting stroke - Paddlers use this stroke for stability - Top hand mid to low, paddle pressing on water	- Usually, no observable effect on boat - Can be used to angle the boat	Balance stroke	
Punt	- Tip of blade in contact with the bank or other solid obstacle - Pushing action along length of blade	- Usually used for turning, but also propulsive	Forward varied Turn varied	
Side draw	- Blade facing inwards, parallel to boat (more open) in line with body of paddler - Top hand kept high - Blade drawn towards the middle of the boat	- No real propulsion. - No real change in direction - Boat moves sideways	Sideways 100%	

Table II – *continued*

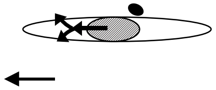
Stroke Name	Description	Effect on boat	Stroke effect	Stroke diagram
Steering	- Position is the same as the start of a draw or the end of a sweep (blade parallel to boat) - Blade not moved, used like a rudder - No propulsion	- Steering / guiding boat - No real propulsion - Can be used to turn the boat or used to keep the boat tracking straight	Guiding stroke Turn 100%	

Table III. Stroke definitions – multi-strokes.

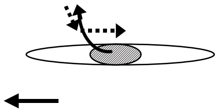
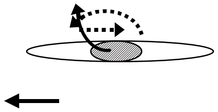
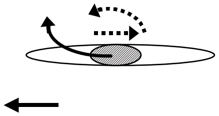
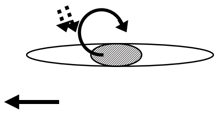
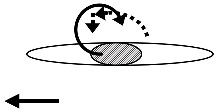
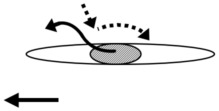
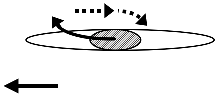
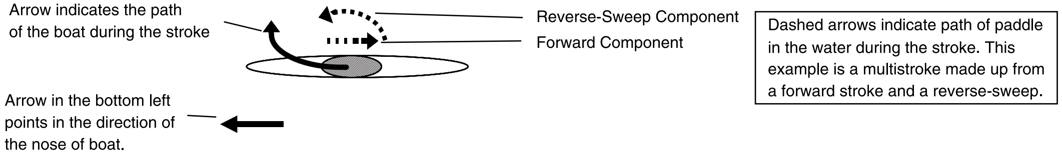
Stroke Name	Description	Effect on boat	Stroke effect	Stroke diagram
Draw-forward	- Combination of a draw stroke followed by a forward stroke - 1. Draw - 2. Forward	- Turns the boat and then propels it forward	1. Turn 100% 2. Forward 100%	
Reverse sweep-forward	- Combination of a reverse sweep stroke followed by a forward stroke - 1. Reverse sweep - 2. Forward	- Turns the boat and then propels it forward	1. Turn >90% 2. Forward 100%	
Forward-reverse sweep	- Combination of a forward stroke followed by a reverse sweep stroke. - 1. Forward - 2. Reverse Sweep	- Propels the boat and then turns it	1. Forward 100% 2. Turn >90%	
Draw-draw	- Combination of two draw strokes with a cutting slicing action between to return the blade to the starting position - 1. Draw - 2. Draw	- Turns the boat a large number of degrees	1. Turn 100% 2. Turn 100%	
Reverse sweep-draw	- Combination of a reverse sweep stroke followed by a draw stroke - 1. Reverse sweep - 2. Draw	- Turns the boat a large number of degrees	1. Turn 100% 2. Turn <90%	

Table III – *continued*

Stroke Name	Description	Effect on boat	Stroke effect	Stroke diagram
Draw-sweep	- Combination of a draw stroke followed by a sweep stroke - 1. Draw - 2. Sweep	- Turns the boat one direction and then turns it back again - Used mainly for gate where the paddler travels across the flow	1. Turn 100% 2. Turn >90%	
Forward-sweep	- Combination of a forward stroke followed by a sweep stroke. When the blade comes in line with the body, the blade is pulled towards the boat (squeeze) - 1. Forward - 2. Sweep	- Propels the boat and then turns it	1. Forward 50% 2. Turn 50%	
Major-minor	- A combination of two strokes which cannot be described as one of the existing multi-strokes. For example: - 1. Brace - 2. Sweep	- Causes a variety of movements depending on the phases being combined and their relative contribution to the stroke	Varied	
Key to stroke diagrams				

Dashed arrows indicate path of paddle in the water during the stroke. This example is a multistroke made up from a forward stroke and a reverse-sweep.

Key: Boat as viewed from above

draw, and steering (Table II). 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 the predominant action of that stroke.

Multi-strokes were defined as strokes in which the paddler did not remove the blade from the water before performing a second type of stroke. In some circumstances, 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 that consists of a draw followed by a forward stroke, in which 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 the C1 paddle stroke; each time the 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 then there was a re-application of pressure, even if the blade did not leave the water, a new stroke was counted. This was a result of C1s' 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 are as follows: draw-forward, reverse sweep-forward, forward-reverse sweep, draw-draw, reverse sweep-draw, draw-sweep, forward-sweep, and major-minor strokes (Table III).

The definition for the starting time for a turn used in this study was the corresponding time when the boat was at right angles to the water flow and then the boat continued to turn beyond this point. The end time of a turn was noted when the boat was again at right angles to the water flow. For example, turning upstream for an upstream gate and then return to pointing downstream has two turning points, one before and one after the gate.

Reliability

One competition run from four national-standard canoe slalom paddlers in an Australian national selection race were filmed using two Sony® digital video cameras (DSR-PDX10P PAL). The four runs included one men's kayak (K1), one women's kayak (K1W), and two canoe (C1) runs. One camera was positioned to capture the top half of the course and the second camera was positioned to capture the bottom half of the course. Each camera was situated in the best position to view its respective section of the course, while overlapping with the other section. These cameras recorded onto Sony® digital video cassettes (DVM60) and were time stamped to an accuracy of 1/50 s. To aid analysis, the paddler was continuously framed using the zoom and pan so that they filled the frame and the shutter speed for both cameras was set to faster than 1/1000 s. This footage was subsequently captured onto computer using video-editing software capable of producing a sample rate of 25 Hz.

Table IV. Example of raw data.

Gate	Gate splits (s)	Turn times (s)	Points	Penalty	Penalty time (s)	Left strokes	In (s)	Out (s)	Right strokes	In (s)	Out (s)
0	3.2	21.84	Minor	Avoidance	29.12	Forward	3.08	3.84	Forward	4.12	4.68
1	6.84	24.44	50	Miss	44.72	Reverse	4.8	5.56	Forward	5.8	6.16
2	9.76	37.16	2	Touch	68.52	Brace	6.36	7.04	Reverse	7.24	7.88
3	14	45.16				Sweep	8.08	8.72	Forward	8.88	9.48
4	16.48	61.56				Forward	9.76	10.16	Forward	10.44	10.96

Each of the four different trials were analysed three times by each of the three observers using a computer program written by one of the researchers in Visual Basic. This program was written specifically for the analysis of canoe slalom competitions to enable synchronization of multiple videos so that timing for the entire run was continuous and temporal and stroke information could be extracted. There was no preset time limit for analysis of the runs, but initial trials took around 3 h, whereas later trials took around 1 h to complete. These trials were randomized for each observer to reduce any learning effect that might occur during the reliability trials.

The reliability of detecting penalties through video was considered important because human error in judging at competitions results in some penalties being missed and others being awarded when no error was made. Therefore, the video was used to assess penalties so that a comparison of each paddler's true performance could be made.

Data analysis

From each raw data file (Table IV) generated from each run analysed, gate split times, turn times, and stroke information were extracted into three separate tables for each variable. The tables were arranged so that intra-observer, trial, and inter-observer error could be calculated.

Times within- and between-runs could not be compared directly without normalizing the data to a common mean. Therefore, the mean time for each observer was calculated for equivalent data points across their three repetitions. The mean time for all observers across the nine repetitions (three for each observer) was also calculated. The time differences to the means were then used to compare data for synchronization time, gate split times, turn times, stroke in times, and stroke out times. However, before stroke in and stroke out of water times could be analysed, both left and right were combined into one list based on time; strokes were then matched for time in and out for each trial.

To determine the reliability of the stroke identification for both intra-observer and inter-observer analysis, the numbers of matching stroke identification responses were expressed as a percentage of the total number of stroke identification responses. If the strokes matched exactly, they were classified as correct strokes. However, it was also possible to have a half-correct identification by either identifying only one part of a multi-stroke or combining a pure stroke into a combination stroke. The percentage of half-correct strokes was then divided by 2 to weight them lower than correct strokes. Correct strokes and half-correct strokes were then added to give the total percentage of correct strokes.

To assess the reliability of penalties and identification of avoidance, a similar method to that used for stroke identification was used, but without half-correct identifications. Using the two categories "avoidance" and "no avoidance", the rate of correct identification was

Table V. Intra-observer variation (all values presented in seconds).

	Synchronization	Gate split	Turn times	Stroke in	Stroke out
Mean	0.00	0.00	0.00	0.00	0.00
Minimum	−0.05	−0.45	−0.63	−0.40	−0.43
Maximum	0.03	0.53	0.59	0.35	0.59
Range	0.08	0.99	1.21	0.75	1.01
Standard deviation	0.01	0.11	0.11	0.04	0.04
Total error of the measurement	0.01	0.08	0.08	0.03	0.03
Limits of agreement	0.03	0.21	0.21	0.07	0.08

Table VI. Inter-observer variation (all values presented in seconds).

	Synchronization	Gate split	Turn times	Stroke in	Stroke out
Mean	0.00	0.00	0.00	0.00	0.00
Minimum	−0.06	−0.92	−0.76	−0.53	−0.76
Maximum	0.03	0.80	0.80	0.60	0.84
Range	0.08	1.72	1.56	1.13	1.60
Standard deviation	0.02	0.20	0.19	0.06	0.05
Total error of the measurement	0.01	0.14	0.13	0.05	0.04
Limits of agreement	0.04	0.39	0.37	0.13	0.11

assessed based on the majority of identifications for each gate. The percentages of major and minor avoidance were compared for avoidance and no avoidance.

Statistical analysis

For all time-related variables, the mean, minimum, maximum, range, standard deviation, error of measurement, and limits of agreement were calculated and used to indicate the variability and reliability of the data. Limits of agreement indicate the minimum difference between analysis trials that was not considered error of measurement. Normalization of the data resulted in the mean always being calculated as zero.

Results

Intra-observer analysis resulted in less variation for all variables than inter-observer analysis. This trend was observable in the range, standard deviation, total error of the mean, and the limits of agreement for each variable. The data for the video synchronization point showed the least variation. The limits of agreement were 0.03 and 0.04 s for the intra-observer and inter-observer analysis respectively (Tables V and VI). Gate split-times and turn times

Table VII. Average intra-observer stroke identification.

Stroke type	Number of strokes	Percent of correct strokes	Percent of half-correct strokes	Percent of correct strokes + half/2
Brace	26	82	4	84
C	3	70	0	70
Draw	17	80	11	85
Draw-draw	2	72	11	78
Draw-forward	34	86	5	89
Forward	217	95	2	96
Forward-reverse sweep	1	33	33	50
Forward sweep	4	58	8	63
Multi	16	72	18	81
Reverse sweep	2	61	6	64
Reverse sweep-draw	1	100	0	100
Reverse sweep-forward	7	95	3	97
Reverse	1	100	0	100
Steering	5	61	0	61
Sweep	27	81	4	83
Tap	6	80	0	80
All strokes	355	89	4	91

Table VIII. Inter-observer stroke identification.

Stroke type	Number of strokes	Percent of correct strokes	Percent of half-correct strokes	Percent of correct strokes + half/2
Brace	12	52	9	56
C	1	33	0	33
Draw	18	65	15	72
Draw-draw	1	44	44	67
Draw-forward	43	62	14	69
Forward	240	85	4	88
Multi	11	51	28	65
Reverse sweep	1	22	0	22
Reverse sweep-draw	1	33	33	50
Reverse sweep-forward	8	78	21	88
Steering	1	67	0	67
Sweep	22	73	5	76
Tap	5	69	0	69
All strokes	364	78	7	81

showed similarities in variation. In the intra-observer analysis, the limits of agreement for both gate-split times and turn times was 0.21 s. For inter-observer analysis, the limits of agreement for both gate split-times and turn times increased to 0.39 and 0.37 s respectively (Tables V and VI). Stroke in and out of water times revealed similar variation. Limits of agreement increased from 0.07 and 0.08 s for stroke in and stroke out in the intra-observer analysis to 0.13 and 0.11 s respectively in the inter-observer analysis (Tables V and VI).

Intra-observer analysis of stroke identification for all trials revealed that C, draw-draw, forward-reverse sweep, forward-sweep, reverse sweep, reverse sweep-draw, reverse sweep-forward, reverse, taps, and steering strokes recorded ten or less occurrences each out of the 355 strokes analysed (Table VII). This compared well with the inter-observer analysis, in which 364 strokes were identified, but three fewer categories: forward-reverse sweep, forward-sweep, and reverse strokes. The percentage of correct identifications for strokes identified fewer than ten times was generally low, but ranged from 22% for reverse sweep to 100% for reverse sweep-draw and reverse strokes (Tables VII and VIII).

Values for strokes correctly identified more than ten times in the intra-observer analysis were 72% for multi-strokes, 82% for braces, 80% for draws, 81% for sweeps, and 86% for draw-forwards (Table VII). For inter-observer analysis, these values were 51% for multi-strokes, 52% for braces, 65% for draws, 73% for sweeps, and 60% for draw-forwards (Table VIII). Half-correct strokes improved all these strokes by 1–16.5%.

Table IX. Avoidance – stroke identification.

Penalty	Intra-observer (average)	Inter-observer
Minor avoidance	91	83
Major avoidance	81	69
No avoidance	94	91
No avoidance – minor avoidance	83	83
Errors due to major avoidance	17	17
Touched gates	100	100
Missed gates	None recorded	None recorded

Forward strokes made up more than 60% of the total number of strokes and these were identified correctly between 85% of the time for inter-observer analysis and 96% of the time for intra-observer analysis including half-correct strokes. Intra-observer analysis recorded 355 strokes that were identified correctly 89% of the time; this increased to 91% with the inclusion of half-correct strokes. Of the 364 strokes recorded for inter-observer analysis, 78% of the time the strokes were identified correctly; this increased to 81% with the inclusion of half-correct strokes (Table VIII).

Only one penalty (touch) was detected in the analysis and this was identified correctly in all trials by all observers. Detection of when no avoidance occurred was greater than 90% correct. Minor and major avoidances were detected correctly more than 80% of the time for intra-observer analysis and 70% of the time for inter-observer analysis. When no avoidance was detected, 83% of errors resulted from minor avoidance being detected and the other 17% of the time because major avoidance was detected (Table IX).

Discussion and implications

This study determined the intra-observer and inter-observer reliability for time–motion analysis of canoe slalom competition using a specific definition set. The dependent variables used in this research to assess reliability were related to the time at which each event occurred in addition to the classification of each of these events.

Analysis of stroke identification revealed that the ability of observers to identify strokes correctly was greater than 78% (the mean inter-observer value), which compared favourably with previous literature on gait and association football that involved the identification of far fewer categories. However, comparison with other sports and previous research is hindered by the unique characteristics of slalom canoeing, in particular water and waves which cause visibility problems.

Half-correct strokes indicated the number of multi-strokes that were not identified correctly but still contained part of the correctly identified stroke in them. Results indicated some confusion about the identification of multi-strokes because of their complexity. This may have been accentuated by long multi-strokes being broken at slightly different points and, therefore, presenting as different strokes in the final analysis. Further training of observers may assist in improving this aspect together with consultation to clarify difficult-to-categorize strokes.

Comparison of the number of stroke identifications and the percentage of correct stroke identifications indicated a trend between low identification counts and low reliability in identification. We believed that if a trial was to include many of these strokes, then the identification reliability would more closely match the identification reliability for all strokes.

The level of detection for penalties (touched gates and missed gates) was exceptional. However, this would be anticipated to decrease for analysis in windy conditions, when gates are splashed and when touches are less distinctive. Observers were able to detect successfully when avoidance had and had not occurred and were able to categorize the type of avoidance that had occurred. This allows useful information about the paddlers' lines – the path the boat took – to be assessed.

The variation recorded for stroke in and out times was less than the variation for gate split-times and turn times owing to the ability to use the paddle position relative to the water as a reference for stroke in and out times. Camera angles for each gate influenced the accuracy of the splits that could be measured off each gate, thereby increasing the variation in gate split-times and turn times. The reliability for the times recorded for stroke in and out positions, gate splits, and turn times was believed to be lower than for land-based equivalents such as running or skiing because of the number of times that waves obscured critical measurement components. In addition, some of the filming for this study was not as tightly zoomed as recommended for optimal analysis; therefore, further improvement in analysis would also be expected because of improved filming.

Results from all variables revealed that intra-observer analysis was more reliable than inter-observer analysis. This probably resulted from slightly different interpretations of the definitions and differences in the knowledge of canoe slalom among the observers. All three observers in this study were relatively inexperienced in the use of the system and the definition set used for the analysis, because the definitions, analysis method, and analysis system specific to canoe slalom were only developed just before the study. Although some trials were completed before the reliability study, we recognized that learning was still ongoing. Therefore, the reliability for both intra-observer and inter-observer analysis would improve further for all variables after the completion of this study.

Applications for this analysis technique include the comparison of an individual's performance to top paddlers at the same competition, and comparison of multiple runs from an individual to determine the impact of various techniques or strategies on their run time. This analysis method can also be used to characterize top performers at a competition and compare performances from competition to competition to determine the effect of various courses on an individual's performance and strategies.

Application of this method of competition analysis will result in performance improvements through the discovery of the methods, strategies, and techniques that top performers use. Although each paddler has his or her own strategy, comparison between individuals using this analysis method will highlight where an individual can gain time through using different strategies. Linking strategies and techniques to run time allows paddlers to quantify the effect of different strategies. This allows them to determine objectively the fastest technique.

Further research topics relating to the current investigation could include determining the ability of a standard video camera (25 Hz) to detect changes in performance in high-standard athletes, detailing the characteristics of top canoe slalom paddlers from international competition, and determining the influence of venue and competition on the techniques, performances, and strategies of top canoe slalom performers. This analysis could also be used to assess the strategies an individual uses, and to determine aspects that could be improved through the adoption of alternative strategies and the impact of these changes for an individual.

For performance analysis to be effective, it has to be capable of detecting differences between high-standard athletes and longitudinal changes in these athletes. This research is the first step in demonstrating that competition analysis is effective for canoe slalom, as it shows that the analysis technique for canoe slalom is reliable. Further research that applies this method is required to determine the ability of the method to detect differences in high-standard athletes.

Conclusion

The reliability of all the variables analysed in this study was considered to be acceptable and compared favourably with previous research on gait and association football that used fewer variables. The definitions, analysis method, and analysis system specific to canoe slalom were novel; we recognized that the performance analysts were still learning. Therefore, we anticipate that the reliability of these performance analysis techniques would further improve with further practice after the completion of this study.

Intra-observer analysis for all variables assessed in the current investigation demonstrated greater reliability than inter-observer analysis. This most likely resulted from individual differences in interpretation of definitions in addition to experience of the operators. Therefore, to obtain the greatest accuracy and repeatability from such an analysis, a single observer should complete all analyses.

This research is the first step in demonstrating that competition analysis is effective for canoe slalom. Further research that applies this method is required to determine the ability of the method to detect differences in high-standard athletes.

Acknowledgements

We would like to thank the following people for their contribution to this project: Mike Druce, Myriam Fox, Daniel McFarlane, Keith Lyons, and Margi Bohm.

References

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* (p. 78). Brisbane: The Conference.

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

Hughes, M., Cooper, S. M., and Nevill, A. (2002). Analysis procedures for non-parametric data from performance analysis. *International Journal of Performance Analysis in Sport*, *2* (1), 6–20.

Hughes, M., and Bartlett, R. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences*, *20*, 739–754.

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. Clarys, and A. Stibbe (Eds.), *Science and football* (pp. 274–281). London: E & FN Spon.

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

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