# Abstract

*Objectives:* Investigate how whitewater kayakers' perceptual-cognitive skills vary as a function of their expertise; Show that web-based simulation can be a useful tool to study perceptual-cognitive expertise.

*Design:* Cross-sectional study.

*Method:* Self selecting participants (N=180, age 38.5, SD 13.7) took part in a web-based anticipation task. Prior expertise was measured using a questionnaire, from which participants were assigned into three groups. Participants then viewed a sequence of videos taken from the perspective of a kayaker travelling down rapids, and were asked to identify safe areas of still water (eddies). The videos were shown under two different conditions;

1.) *Read and run* – video only.
2.) *Inspec*t – participant views an image of the whole rapid prior to watching the video.

The number of eddies identified, the number of eddies misidentified and the response times were recorded.

*Results:*. Under the read and run condition the number of eddies identified increases $F(2, 163)= 10.95$, $p<.0005$, partial $\eta^2 = .12$, the number of eddies misidentified increases and response time decreases $F(2, 163)= 7.03$, $p=.001$, partial $\eta^2 = .08$ with increasing expertise. Under the inspect condition, response time decreases $F(2, 147) = 17.83$, $p<.0005$; partial $\eta^2 = .18$ and eddies hit increase non-significantly with increasing expertise.

*Conclusions:* The ability of white water paddlers to interpret and anticipate their environment increases with expertise. Better paddlers don't just paddler better – they exhibit better perceptual- cognitive skills.
We believe that this research has demonstrated that web-based simulation is a viable methodology to study perceptual-cognitive expertise.

**Table of Contents**

The very best performers in sport seem to dance through their environment, perceiving opportunities and making just the right movements to take advantage of them. During a cricket match, a batsman recognises a faster delivery and deftly drives the ball into a space between two fielders; on a huge rapid, a whitewater kayaker arrives at a surging wave with the perfect combination of timing, speed and direction for the wave to throw her across across the river towards her intended destination. Researchers have sought to discover just what enables the expert performer to do just the right thing, in the right place at the right time.

Early studies (e.g. Banister & Blackburn, 1931), suggested that generic abilities such as response time or visual acuity lay behind these expert performances, but later research (e.g. Helsen & Starkes, 1999, Mann, Abernethy & Farrow, 2010) provides compelling evidence that this is not the case.

De Groot's influential (1966) experiment briefly exposed expert and intermediate chess players to both meaningful (i.e. that might occur within a game) and random arrangements of pieces on a chess board. The experts were found to perceive and hence recall meaningful positions much better than intermediates, but this difference disappeared when the pieces were arranged randomly. Later research (De Groot & Gobet, 1996) showed that intermediates tended to simply recall the positions of individual pieces on the board, whilst experts were more likely to recall strategically important constellations of pieces, along with their attendant threats and opportunities. This suggests that experts perceive their environment in a different way to intermediates, and that these perceptual differences may contribute to their superior performance.

**Perceptual-cognitive skill**

Perceptual-cognitive skill refers to the ability of an individual to process environmental information in order to select and execute appropriate actions (Martenuik, 1976). Ericsson et al. (1991, 1996, 1998, 2003, 2005) assert that expert performers exhibit a higher level of perceptual-cognitive skill than their less experienced counterparts; that this is part of what underlies their higher level of performance; and that perceptual-cognitive skills are developed through relevant purposeful practice.

The relationship between perception-cognition and expert performance has been conceptualised in two contrasting ways. The information processing approach (e.g. Martenuik, 1976), asserts that perception is an indirect process in which an expert's superior internal representation of their performance environment allows them to give meaning to incoming environmental information more efficiently than novices. That internally represented knowledge is built up through practice and experience. In contrast, the ecological dynamics approach assumes that a performer directly perceives opportunities to act in their environment (*affordances*) with no recourse to internal representations. Meaning resides in the relationship between the performer and their environment. An expert's superior performance is a result of being better attuned to the affordances offered by their environment (Dicks, Araujo & van der Kamp, 2019).

Most perceptual-cognitive expertise research has taken one these two viewpoints (albeit often implicitly). Despite their different conceptualisations, both approaches make the same prediction; that experts will make better decisions, more rapidly than other performers.

A substantial body of research across performance environments as diverse as music (e.g. Waters, Townsend & Underwood, 1998), medicine (e.g. McRobert et al. 2013) and the military (e.g. Vartanian, Cody & Blackler, 2016) has found that expert performers do indeed exhibit better perceptual-cognitive skills (e.g. anticipation, decision-making) than novices. These skills are often specific to their environments and not directly transferable to other domains (Drowatzky & Zuccato, 1967, Williams et al. 1993).

Within sports such as Football (Williams et al. 1994), Cricket (Mueller et. al. 2006), Badminton (Wright et al., 2010), Tennis (Farrow & Abernethy, 2003), Ice Hockey (Salmela & Fiorito, 1979), Volleyball (Wright et. al., 1990) and Baseball (Ranganathan & Carlton, 2007), research has shown that experts respond faster and more accurately than intermediates and novices. However, the overwhelming majority of this research has studied team or racquet games (e.g. Williams *et. al* 1994, van Maarseveen et al. 2018), in which expert performance involves anticipating the actions of other participants, who may intentionally conceal or even provide misleading cues (Güldenpenning et al., 2017).

In contrast adventure sports usually involve an individual participant interacting with the natural environment. In whitewater kayaking the “opponent” (or on a better day, the teammate) is the river. There is a dearth of research investigating perceptual-cognitive expertise within adventure sports with just one published paper (Furley & Dorr, 2016) studying wave choice within surfing and one conference poster (Novak et al., 2016) examining route selection in mountain biking.

Furley & Dorr (2016) state that “it seems likely that the theorizing of Ericssson and colleagues further applies to activities such as reading river currents in kayaking” (p. 70). Our research aims to determine if this is the case.

**Whitewater kayaking**

White water kayaking involves paddling short, manoeuvrable kayaks down rapids on either natural rivers or artificial white water courses (Ferrero, 2002).

The technical difficulty and potential consequences of a rapid a rapid are described by the International Canoe Federation (1979) whitewater rating scale which grades a rapid from 1 (gentle, smooth flow, where the kayak can take any route down the river) to grade 6 (pressure waves, whirlpools and waterfalls at the limit of navigability).

A rapid that appears to the novice as surging and unpredictable resolves itself for an expert into a sequence of features which will act in a predictable manner on the boat and can be used to help the paddler navigate the rapid. As Neally (1986) states “how well a boater can read the topography of this complex terrain...can make the difference between a good run and a bad run, occasionally between life and death” (p. 20). Paddling a complex rapid has been likened to playing a game of three dimensional chess. “Whitewater kayaking is as much a game of strategy as it is a sport” (Whiting & Varette, 2008, p. 146). This is not just true within the non-competitive recreational disciplines. At the very highest levels of the sport, Nouria Newman (slalom, freestyle and extreme race champion) said of Aniol Serassolses (extreme race champion and expedition paddler), “I’d like to be in his brain for a river - to see what he sees - ’cos I think he just perceives things differently” (Newman, 2018).

Although it is well accepted across all levels of the sport that whitewater kayaking is a much a cognitive as a physical pursuit, there is currently no empirical research that has studied the degree to which perceptual-cognitive skills contribute to whitewater kayaking expertise. Previous research has been limited to the physiological (e.g. von Someren et al. 2000, Michael et al., 2008) and technical (e.g. Beatriz et al., 2014, Brown et. al., 2011) aspects of kayaking, and has taken place predominantly within the Olympic discipline of flat-water sprint.

One ubiquitous river feature is the eddy. As Berry (1989) states, “an eddy is a pool of flatter and calmer water...these are usually found behind rocks or sections of the river bank that stick out into the flow...Eddies are relatively secure places in which to rest or look at the next bit of river” (p. 285).

Being able to recognise, get into and out of eddies is a fundamental skill that is required at all levels of whitewater kayaking and is often one of the first moves that coaches work to develop in novices. Getting out of the main flow into an eddy (also known as “hitting the eddy”, “attaining the eddy” or “breaking out”) requires the paddler to recognise the eddy well in advance and start driving the boat towards it. It is common for kayakers, paddling at the limits of their ability, to fail to recognise the eddy in time, which results in them being swept downstream past it often facing backwards.

When tackling a straightforward familiar rapid, a kayaker would typically adopt a *read and run* strategy, paddling on down the rapid, always having at least one attainable eddy available to stop if required. For more difficult or unknown rapids, a paddler would typically stop, get out of their kayak and *inspect* the rapid from a more elevated viewpoint before attempting to paddle it. To effectively navigate the rapid, the paddler needs to reproject the visual display from their elevated frame of reference into a paddler’s eye view of the river. This cognitively demanding task (Mou et al. 2004) may be one of the perceptual-cognitive skills that underlie expert white water kayaking.

## Research Design

Williams and Ericsson (2005) identified three main approaches to researching perceptual-cognitive expertise in sport. Capturing expert performance (developing reliable measures of both performance and expertise, and developing representative tasks by which they can be correlated); identifying the underlying mechanisms that enable expert performance; investigating how perceptual-cognitive expertise is developed and how to help develop it.

Most of the existing research fits into the first category of capturing expert performance and a variety of metrics have been developed to measure perceptual-cognitive skill; most commonly response time, response accuracy and eye tracking measures. The research has taken place using a range of different tasks; typically timed response (e.g. Nakamoto & Mori, 2008), recall (e.g. Gygax et al., 2008, McPherson, 1999), decision-making (e.g. Del Villar et al., 2007), temporal occlusion (e.g. Jackson, Warren & Abernethy, 2006, Farrow, Abernethy & Jackson, 2005) and spatial occlusion (e.g. Williams & Davids, 1998, Williams et al., 2006). Different means have been used to present the representative stimuli, from static pictures, through to video (Williams & Davids, 1998), virtual-reality (e.g. Brault et. al 2012) and a very small number of in-situ experiments (Dicks, Button & Davids, 2010 and van Maarsevenn et al. 2018).

The majority of research into perceptual-cognitive expertise (including this study) has utilised the expert versus novice paradigm (Baker et al., 2017) within a cross-sectional study design. In this approach two groups of participants are selected from opposite ends of the expertise spectrum and between-group performance is compared. This gives the researcher the greatest likelihood of detecting a difference in performance between the groups, but Abernethy, Thomas & Thomas

(1993) point out the limitations of this approach; positive results show that experts demonstrate higher levels of perceptual-cognitive skill than novices, but do not show that this higher level of skill is itself the cause of their expertise, nor how this higher level of skill is acquired. Indeed van Maarseveen et al. (2018) have shown that perceptual-cognitive tests in footballers do not predict in game performance, suggesting that the relationship between at least some perceptual-cognitive skills and expertise might be correlative rather than causal.

Two more limitations, most commonly noted by researchers utilising an ecological dynamics approach (e.g. Craig, 2013, Dicks, Araujo van der Kamp, 2019) are the lack of *ecological validity* and the breaking of *perception-action coupling* that is present within most studies. Ecological validity refers to the completeness (or otherwise) of the environmental information provided by the representative task and the authenticity of the interaction between the participant and the simulated environment (see Pinder et al., 2011 for a more detailed discussion). For example, viewing a video of whitewater kayaking does not offer the same cues as a real river. Footage taken from the river bank does not provide the same information as a paddler's eye view, the screen fails to offer any three dimensional depth, speakers fail to capture the nuances of the river's noise and a body sat passively in front of a screen doesn't receive any of the kinaesthetic feedback through the paddle that is crucial to real life performance. Acting by pressing buttons or clicking a mouse is not the same making the whole body movements that the majority of sports demand. Perception-action coupling refers to the cyclical relationship between incoming environmental information and movement. As Gibson (1979) stated "We must perceive in order to move but we must also move in order to perceive". In the overwhelming majority of research the links between input and output are broken; the visual information that the a participant receives whilst viewing the a video unfolds in a pre-determined manner that is not linked to their actions. This is a valid criticism of both laboratory and web-based simulation. Virtual reality technology offers a way to retain control over all the environmental cues without breaking perception-action coupling, but it does so with far greater costs in equipment and development time  (Neumann *et al*, 2017).

As Williams and Ericsson (2005) state, "most scientists would aspire to carry out well-designed and controlled experiments with good ecological or external validity. The issue of contention is the extent to which individuals are willing to loosen their grip on the former to achieve gains in the latter" (p. 287).

The availability of inexpensive rugged head-mounted cameras (*headcams*) enables the capture of authentic video footage from many performance environments. In this research I have developed a web-based simulation of whitewater kayaking using headcam footage which I hope offers a useful middle ground between laboratory based research with small sample sizes which is so well controlled that the results might not retain their validity outside of the laboratory and *in-situ* work with technological challenges and so many confounding variables that it becomes diificult to establish correlation.

Within this study I hypothesize that more expert paddlers will demonstrate higher levels of perceptual-cognitive skill then their novice counterparts.
Specifically, I anticipate that they will;
1.) Identify more eddies;
2.) Identify eddies more quickly;

I expect the hypotheses to apply both when the paddler adopts a read-and-run strategy, (paddling straight down the rapid), and when the paddler inspects the rapid prior to paddling it.

I hope this study will show that web-based simulation is a viable approach for the study of perceptual-cognitive expertise within sport.

I will also determine if any performance improvement can be detected over the course of the simulation, with a view to its potential use as a training tool.

## Method

### Participants

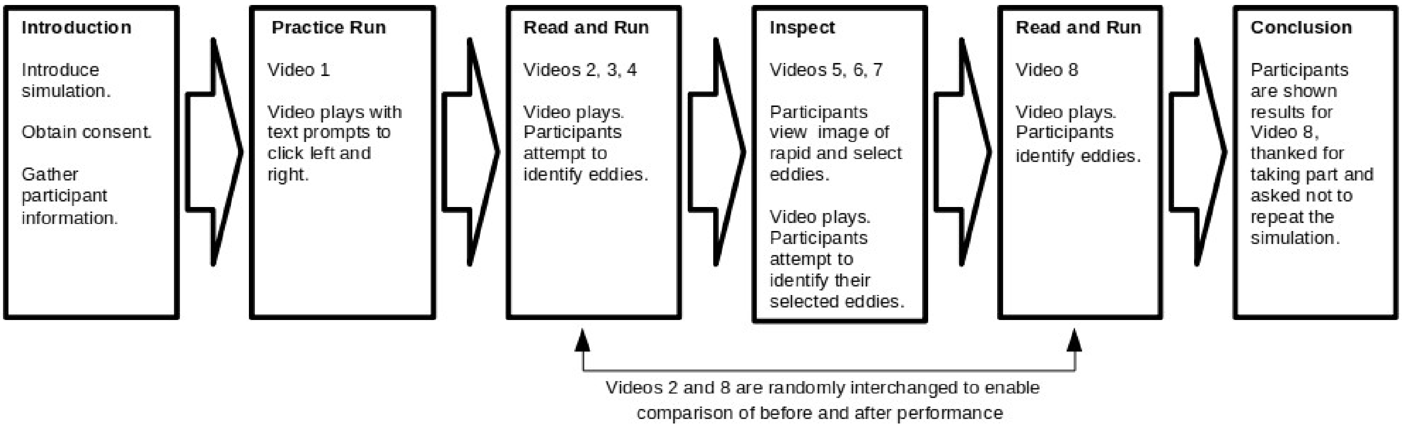
180 self-selecting recreational white water paddlers aged from 18 to 71, with experience ranging from 1 to 50 years of paddling, paddling 1 to 330 days per year and paddling rapids ranging from grade 1 to grade 5 chose to take part in the online simulation. Descriptive statistics are shown in table 2.

### Procedure

Participants were recruited online via whitewater kayaking social media groups. The simulation was hosted online at http://www.georgefell.co.uk/Msc/Msc.htm and participants took part using their own devices at a time of their choosing. Over the period in which the data was gathered (15 days), the simulation was run 193 times. 13 of those runs were assumed to be repeats by the same individuals (same age, same IP address). For these individuals, their initial runs were retained, but their repeated runs were excluded from the analysis.

The overall structure of the simulation can be seen in fig. 1 and the source code can be seen in appendices 1 and 2.

Figure 1. Schematic of the simulation structure.




On visiting the webpage, participants provided limited personal information (age, number of years paddled, number of days paddled per year, grade paddled, prior knowledge of the rivers used in the simulation) and provided informed consent for their participation and the use of their data (in line with University of Stirling guidelines).

The participants then viewed the practice video, during which text was intermittently superimposed over the footage, prompting the participant to make the same left and right mouse, screen or keyboard inputs (hereafter referred to as “clicks”) that they would use to indicate eddies in the subsequent videos. The aim of the practice video was both to familiarize the participants with the input method they would be using and also to identify and exclude any participants using devices where their recorded response time (in reality a sum of their actual response time and the latency of their device) was too long or too variable to be of use in the study. It transpired that there were no outliers, so no participants were excluded on this basis and the data collected from this practice run were not used any further

The next three videos were shown under the read and run condition.  After a countdown the video played straight through, to simulate paddling straight down a rapid, and the participant clicked to identify eddies on the left or right side of the river as they became visible.

The following three videos were shown under the inspect condition. Here the participants viewed a static image of the rapid taken from an elevated perspective. They were asked to click on the image to choose a sequence of eddies that it would be reasonable to paddle into. They then viewed the video and attempted to identify the eddies they had chosen. This was done to simulate inspecting a rapid prior to paddling it.

The final video was shown under the read and run condition. Videos 2 and 8 (see fig. 1) were interchanged for half the of the participants, in order to allow the evaluation of any performance change over the course of the simulation.

After the final video a page was displayed thanking the participant for taking part, displaying the results from their final run and asking them not to repeat the simulation

**Data Collection**

The participants personal data, plus their device, browser and IP address were stored on their browser. As the videos played, data describing each click (left or right, and time elapsed since the start of the video) were also logged, as were the x and y co-ordinates of any image clicks made under the inspect condition. This was done using a JavaScript written specifically for this study (see appendix 1). As Byrne, Heaveya & Byrne (2010) point out, running the simulation on the participants browser minimizes the risk of network delays (latency) affecting the results.

At the end of the simulation the data were sent to a server-side perl script (see appendix 2). Each participant's data was compared to reference data, detailing which side of the river each eddy was on, the time ranges each eddy was attainable and which parts of the images shown under the inspect condition corresponded to which eddies. For each video shown, the script calculated three performance metrics as shown in table 1.

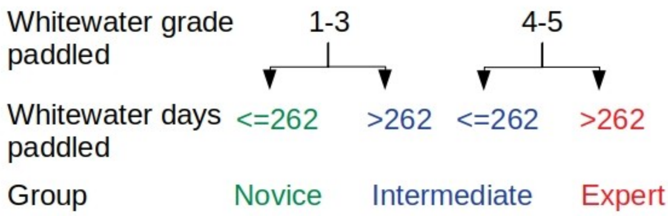
Table 1. Definitions of performance metrics

| | Read and run condition | Inspect condition |
|---|---|---|
| Eddies Hit | How many of the clicks made by the participant actually correspond to eddies on the video. | How many clicks correspond to the eddies the participant had previously selected whilst viewing an image of the rapid. |
| Eddies Missed | How many of the clicks made by the participant do not correspond to eddies on the video. | How many clicks do not correspond to the eddies the participant had previously selected. |
| Response Time | The mean amount of time elapsed between the eddy becoming visible and the participant identifying it averaged over all of the eddies hit on that rapid. | |

## Data Analysis

**Expertise groups.** The participants were sorted into three groups based on a combination of their prior experience and the grade of whitewater that they paddle as shown in fig. 2.

Figure 2. Method for sorting participants into expertise groups.




There is a step change in both risk and technical requirements between grade 1-3 rapids and grade 4-5 rapids, so it seems valid to split the group by grade this way. The number of whitewater days paddled was estimated by multiplying the participants' self reported number of years paddling and number of days paddled last year. The choice of cut-off at 262 days is arbitrary (although it is close to the median value across the whole cohort) and was chosen to give approximately equally sized groups. The descriptive statistics for the resultant groups are shown in table 2.

Table 2. Descriptive statistics with standard deviations (in parentheses) for the expertise groups.

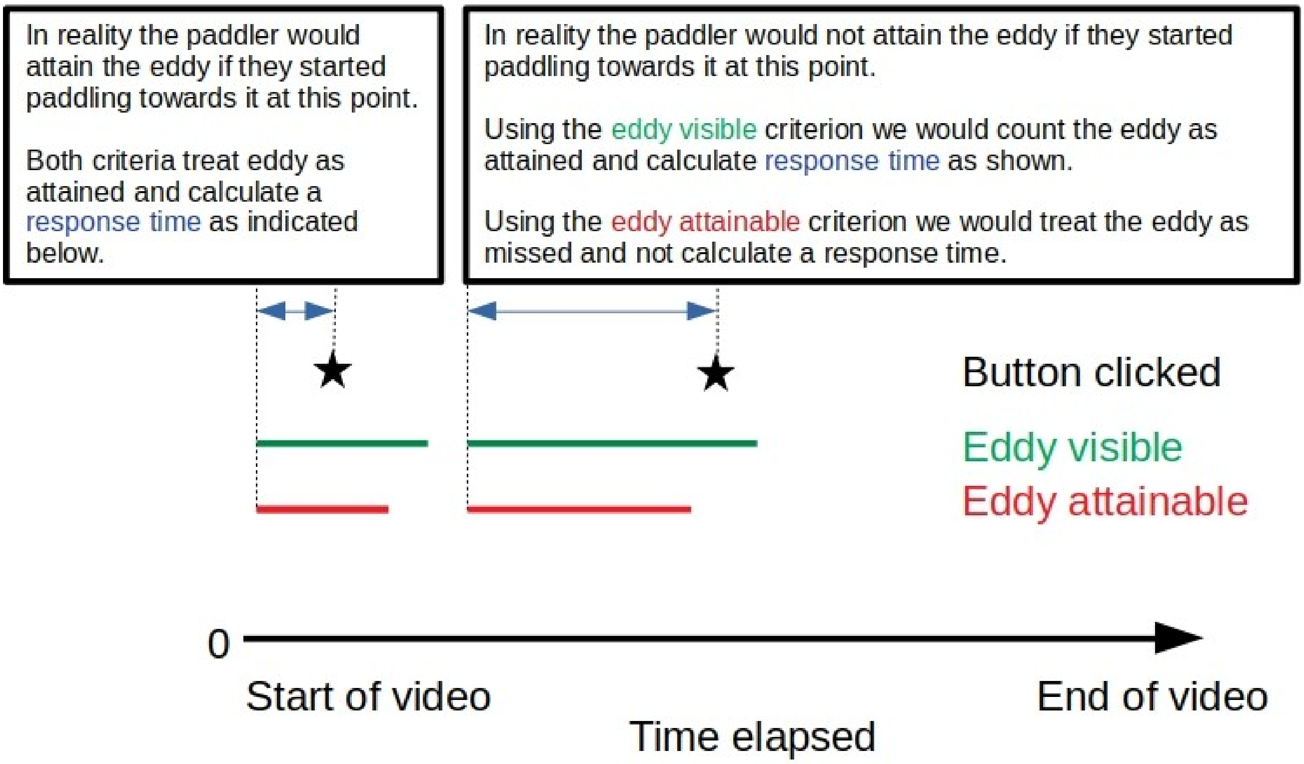
| | Number of participants | Age | | Grade paddled | | Days paddled | |
|---|---|---|---|---|---|---|---|
| Novice | 55 | 38.4 | (14.1) | 2.6 | (.6) | 81 | (65) |
| Intermediate | 71 | 38.5 | (14.1) | 3.2 | (1.1) | 1006 | (2054) |
| Expert | 54 | 38.6 | (12.9) | 4.2 | (.4) | 1523 | (1982) |
| All participants | 180 | 38.5 | (13.7) | 3.3 | (1.1) | 878 | (1770) |

**Preliminary analysis.** During the experiment I discovered that the input buttons did not function on some iPads and the most recent iPhones using the Safari browser. For these 13 participants, no clicks were recorded during any of the videos and their data was not used. Under the inspect condition a further 9 participants did not attempt to identify any eddies on the images. It is unclear if this was due to my software not functioning properly within their browser or the participants misunderstanding the instructions. Their data under the inspect condition were not used.

One further participant was excluded for indiscriminate clicking (a total of 238 clicks during the simulation, with the next highest total being 76). This left $N_{total}$=166 participants under the read and run condition, with the expertise groups composed as follows; $N_{novice}$=51, $N_{intermediate}$=65, $N_{expert}$=50 and $N_{total}$=157 for the inspect condition with the groups split as follows; $N_{novice}$=47, $N_{intermediate}$=56, $N_{expert}$=48. My a priori estimation of minimum sample size for statistical power was $N_{total}$=30.

An initial inspection of descriptive statistics showed between-group differences in line with my hypotheses under the read and run condition, but not under the inspect condition. Splitting the inspect condition data by rapid showed that some rapids did show differences between expertise groups whilst others did not. The rapids that failed to show differences contained sequences of eddies occurring at higher frequencies than the others. Some sections had sequences of consecutive eddies on both sides of the river with only short periods of time between them. Under these circumstances the software might have misidentified a very late click for one eddy as a very early click for the next eddy (or vice-versa). In the simulation I had counted an eddy as attained if the user clicked the appropriate button whilst the eddy was still visible on the screen (see fig. 3). The data was reprocessed, using a tighter criterion under which the eddy was treated as attained only if the user clicked the appropriate button at a point at which it would still be possible to paddle into the eddy. I believe this is a more ecologically valid measure of performance, but also a more subjective one. A stronger or more skilful paddler might still attain an eddy starting from a position on the river at which a less skilful paddler would not. Hence this new criterion has some potential to penalise an expert whilst making no difference to the novice. However, if this effect was important, I would expect the novice–expert group differences to decrease under the new criterion; they did not. To determine the timings of the "last gasp" moments at which each eddy was still attainable, a novice and an expert paddler (the author) independently examined video 5 frame by frame. Our answers differed by no more that 0.3 sec which I deemed an acceptable bandwidth to determine the timings for all the other videos without assistance.

Figure 3. Two different criteria for counting an eddy as hit.




The two stars indicate two separate clicks on the video.
The coloured lines indicate the time windows within which a click would count as having hit the eddy if the eddy was visible (green) and if it was practically attainable (red).
The blue line indicates the response time.

Descriptive statistics are shown for the performance metrics under the read and run condition (table 3) and the inspect condition (table 4).

Table 3. Mean values and standard deviation (in parentheses) of performance measures under read and run condition

| Group | Response Time (s) | Eddies Hit | Eddies missed |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Novice | 2.15 (.49) | 16.22 (5.51) | 10.88 (5.83) |
| Intermediate | 1.91 (.41) | 18.45 (6.82) | 13.62 (8.15) |
| Expert | 1.93 (.26) | 21.72 (5.42) | 17.28 (10.50) |

Table 4. Mean values and standard deviation (in parentheses) of performance measures under inspect condition

| Group | Response Time (s) | Eddies Hit | Eddies missed |
|---|---|---|---|
| Novice | 2.40 (.87) | 3.87 (1.92) | 5.70 (3.40) |
| Intermediate | 1.97 (.93) | 4.09 (2.16) | 5.66 (3.92) |
| Expert | 1.45 (.55) | 4.94 (2.52) | 5.71 (3.76) |

**Confounding variables.** Age and prior knowledge of the rapids were potentially confounding variables. I used a MANCOVA to account for the effects of age, but was unable to treat prior knowledge of a rapid as covariate because for a single participant prior knowledge is not a constant. It varies from rapid to rapid. Instead, separate linear regressions were run on the data from each rapid to examine the effect of prior knowledge on the performance metrics; between-group differences in levels of prior knowledge were calculated and these two quantities were multiplied together to predict the effects of prior knowledge on between-group performance for each rapid. This is in essence what an ANCOVA does at a participant by participant level. Only one rapid (video 6 under the inspect condition) had both a significant effect of prior knowledge on performance and significant between group differences in the level of prior knowledge. That regression predicted that prior knowledge of the river would contribute ~.05 seconds and ~.1 eddies to the difference between the novice and expert group. I deemed that effect to be potentially significant and re-ran the MANCOVA excluding data for video 6 from the 25 participants who reported knowing the river well. This made no difference to the pattern of results, but was sufficient to move the main effect of expertise on eddies hit under the inspect condition into significance. The results presented include all of the data for video 6.

**Assumptions of MANCOVA.** Under the read and run condition there was one outlying datum in eddies hit, four outliers in eddies missed and one in response time (Z-scores 2.8-5.4). The MANCOVA was repeated with these data points excluded, with no change to the significance of the results. The main analysis includes the outliers. All performance measures were normally distributed (with very slight positive skewness) as assessed by visual inspection of Normal Q-Q Plots. Pearson correlation coefficients for the dependent variables all satisfied the $r<0.9$ criterion to exclude excessive multicollinearity (with the highest correlation being $r=0.69$, $p<0.005$ between eddies hit and eddies missed). There were approximately linear relationships between the dependent variables in each expertise group, with the least linear relationships being between response time and eddies in the novice group. Inspection of the scatterplots coupled with the aforementioned correlation between eddies hit and eddies missed, suggest that participants may have used 2 different strategies during the simulation, with one group being profligate with their clicks, resulting in high eddies hit, high eddies missed and low response times across all the groups, whilst another group was more parsimonious with their clicking resulting in more between group variation. There were two multivariate outliers in the data, as assessed by Mahalanobis distance ($p < .001$), however repeating the MANCOVA with these points excluded did not change the significance of the results, so they were retained. The data failed the test of homogeneity of variance-covariances matrices, as assessed by Box's test of equality of covariance matrices ($p < .001$) however with a large sample size and similarly sized groups it is likely that the MANCOVA remains robust.

There were 17 outliers under the inspect condition; 12 for response, two of which were extreme outliers (in one case 10 standard deviations from the mean), none for eddies hit and 5 for eddies missed. Both of the extreme outliers and the majority of the other response time outliers occurred when the participant's mean reaction time was based on just one data point (i.e. they had only attained one eddy). The MANCOVA was repeated excluding all outliers across all dependant variables and gave the same trends, with the same pairwise comparisons reaching significance. The analysis presented includes the outliers. All performance measures were normally distributed (with slight positive skewness) as assessed by visual inspection of Normal Q-Q Plots. There was no multicollinearity between dependent variables, as assessed by Pearson correlation coefficients. Scatterplots indicated less linearity in the pairwise relationships between variables than was the case under the read and run condition. This is perhaps to be expected, especially in the novice group where the number of eddies hit under the inspect condition is both small and an integer and so ceases to behave like a continuous variable. It is important to note that the MANCOVA may have less statistical power under this condition (i.e. there is a greater likelihood of a type II error). There was one multivariate outlier in the data, as assessed by comparing the Mahalanobis distance to a chi-squared ($\chi^2$) distribution with 3 degrees of freedom ($p < .001$), however repeating the MANCOVA with this point excluded did not change the significance of the results, so it was retained. There was homogeneity of variance-covariances matrices, as assessed by Box's test of equality of covariance matrices ($p = .014$). Table 4 shows the descriptive data after the preliminary analysis was completed.

**Main analysis.** Separate univariate MANCOVAs were used for the read and run, and the inspect condition (with age as the covariate) to assess the main effects of expertise. Where significant effects were found, one way ANCOVAs were performed for each dependent variable and pairwise post-hoc comparisons were made. These can be found in tables 5 and 6. A paired samples T-test was used between videos 2 and 8 to assess any change in performance over the course of the simulation. These results can be seen in table 7.

## Results

The results of the main analysis under both conditions and the paired samples T-test are presented below.

### Read and Run Condition

The one-way MANCOVA reported statistically significant differences in the combined performance measures between the different expertise groups, $F(6, 322) = 6.13$, $p<.0005$, Wilk's $\Lambda = .80$, partial $\eta^2 = .103$. Follow up univariate ANCOVAs showed statistically significant effects of expertise on all three performance metrics; for response time $F(2, 163) = 7.03$, $p=.001$; partial $\eta^2 = .08$, for Eddies Hit $F(2, 163) = 10.95$, $p<.0005$; partial $\eta^2 = .119$, for Eddies Missed $F(2, 163) = 7.62$, $p=.001$; partial $\eta^2 = .086$. Post hoc analysis revealed significant between group differences as shown in Table 5. Significant differences between novice and expert groups were reported for all performance measures, with experts responding faster, hitting more eddies and missing more eddies than novices. There were significant differences in the number of eddies hit between all three groups, with the number increasing with increasing expertise.

Table 5. Between group differences and significance under read and run condition.

| Performance Measure | Between Group Comparison | Mean Difference | Significance |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Response Time (s) | Novice - Intermediate | .25* | .001 |
| | Novice - Expert | .23* | .003 |
| | Intermediate - Expert | -.02 | .79 |
| Eddies Hit | Novice - Intermediate | -2.24* | .05 |
| | Novice - Expert | -5.52* | <.0005 |
| | Intermediate - Expert | -3.28* | .004 |
| Eddies Missed | Novice - Intermediate | -2.75 | .08 |
| | Novice - Expert | -6.40* | <.0005 |
| | Intermediate - Expert | -3.67* | .02 |

* indicates significance at the .05 level.

**Inspect Condition**

The one-way MANCOVA reported statistically significant differences in the combined performance measures between the different expertise groups, $F (6, 290) = 6.19$, $p<.0005$, Wilk's $\Lambda = .79$, partial $\eta^2 = .108$.

Follow up univariate ANCOVAs showed a statistically significant effect of expertise on response time $F (2, 147) = 17.83$, $p<.0005$; partial $\eta^2 = .18$, whilst the effect on eddies hit $F (2, 147) = 3.05$, $p=0.05$; partial $\eta^2 = .04$, narrowly failed to reach significance.

Post hoc analyses revealed significant between group differences as shown in Table 6. There were significant differences between experts and novices in response time and number of eddies hit, with novices reacting more slowly and hitting fewer eddies than experts. There were significant differences in response time between all three groups, with response time decreasing with increasing expertise.

Table 6. Between group differences and significance under the inspect condition.

| Performance Measure | Between Group Comparison | Mean Difference | Significance |
|---|---|---|---|
| Response Time (s) | Novice - Intermediate | .43* | .007 |
| | Novice - Expert | .97* | <.0005 |
| | Intermediate - Expert | .54* | .001 |
| Eddies Hit | Novice - Intermediate | -.22 | .62 |
| | Novice - Expert | -1.06* | .02 |
| | Intermediate - Expert | -.84 | .06 |
| Eddies Missed | Novice - Intermediate | .05 | .95 |
| | Novice - Expert | -.07 | .93 |
| | Intermediate - Expert | -.11 | .88 |

* indicates significance at <.05 level

**Practice Effects**

To enable the comparison of performance at the start and end of the simulation, videos 2 and 8 were randomly interchanged and a paired samples T-test (equivalent to a 2 factor repeated measures ANOVA) was used to examine the differences. These are shown in table 7.

Table 7. Performance differences from video 2 to video 8

| Change over simulation | Mean Difference | Significance |
|---|---|---|
| Response Time (s) | .10 | .26 |
| Eddies Hit | -1.74* | <.0005 |
| Eddies Missed | -1.22* | <.0005 |

* indicates significance at <.05 level.

Reaction time deteriorated (non-significantly) over the course of the simulation whilst the number of eddies hit and the number of eddies missed both dropped significantly.

## Discussion

The aim of the study was to investigate how whitewater kayakers' perceptual-cognitive skills vary as a function of their expertise, to discover if performance improved during the course of a web-based simulation and to show that web-based simulation can be a useful tool to study perceptual-cognitive expertise.

The results strongly support my hypotheses that more expert paddlers will;
1.) Identify more eddies;
2.) Identify eddies more quickly;
than novices.

**Response Time**

The findings strongly support the hypothesis that more expert paddlers will identify eddies more quickly than novices. The between group differences were significant under both conditions.

Unlike the other performance measures, beginner to intermediate and intermediate to expert differences are also significant (with the exception of intermediate to expert under the read and run condition). It is tempting to theorise that in the read and run condition, the skill of identifying an eddy is acquired early in a paddler's development. Hence a significant difference between novices and other groups, but no significant difference between intermediates and experts. As the rivers presented were at different grades, this would also suggest that this skill can be learnt on lower grade rivers and transfers to harder rapids. I consider it just as likely that this result is an artefact of the lack of statistical power of this experiment as it is a fresh insight into skill development.

As different sets of videos were viewed under the two conditions, it is not possible to quantitatively compare the response times between conditions. It is at least interesting to note that from the read and run condition to the inspect condition, the response time increases in the novice group, remains similar within the intermediate group and decreases within the expert group (see tables 3 and 4). This would be consistent with the 2004 findings of Mou et al., that mental re-projection is a cognitively demanding task (in this case re-projecting from an elevated viewpoint to the river level, paddler's eye viewpoint) which might take time and practice to develop. Certainly the lower ratio of eddies hit to eddies missed across all groups under the inspect condition compared to the read and run condition suggests that it is a more challenging task than simply identifying an eddy from the river as in the read and run condition. Hence novices may struggle to integrate their internal picture of what they think the eddy will look like from river level with their what they're actually seeing from their kayak whilst experts might have a greater capacity to re-project, encode, store and recall the information they gained from inspecting the rapid. Perhaps novices identify the eddy in the video and subsequently try to determine whether it corresponds to one they have chosen, whilst experts can retain a mental picture of the entire rapid from their inspection, in a manner reminiscent of Chase & Smith's (1973) and De Groot's (1966) work with chess players. This would leave experts primed to anticipate the arrival of each of their chosen eddies in the video. That remains a tentative suggestion and further research (perhaps randomising the conditions under which the videos are shown, coupled with recall tests and a larger sample size) would be needed to demonstrate this empirically.

**Number of Eddies Hit**

Our findings support our hypothesis that more expert paddlers will identify more eddies than novices. This is true under both conditions, albeit the main effect under the inspect condition narrowly fails to achieve significance ($p=.05$) under the main analysis and achieves it ($p=.034$) when data are removed to decrease the confounding effect of prior knowledge.

Beginner to intermediate and intermediate to expert differences are both smaller and less significant (if expertise and performance are correlated and the within group standard deviations are similar, I would expect this to be the case). The direction of change is consistent i.e. eddies hit increases with expertise across all pairwise comparisons under both conditions.

Under the inspect condition the novice – intermediate difference is much smaller than the difference between experts and the other groups. This may suggest that integrating information gained from inspection with on the river information is a skill which takes time and experience to develop, and perhaps on that comes later in a paddler's development.

**Number of Eddies Missed**

Although no predictions were made regarding its behaviour, it is worth considering this variable as it allows us to distinguish between a group achieving more eddies by virtue of more accurate identification versus more eddies due to simply making more clicks.

Under the read and run condition the number of eddies missed increases with expertise, with a statistically significant difference between novices and experts. This suggests that during the simulation at least some of the performance difference in number of eddies hit between novices and experts can be explained by the fact that experts simply made more clicks than novices. It could also be argued that the reason the experts made more false clicks was that they perceived more eddies, but clicked too late attain them. Although the methodology used in this study does not enable direct quantitative comparison between the two conditions, it is interesting to note that the number of eddies missed remained quite constant across the groups under the inspect condition. This is consistent with our previous observation from the read and run scatterplots that some participants used a profligate "click at anything" strategy. This highlights one way in which my simulation is not truly representative whitewater kayaking. On the river a paddler wouldn't repeatedly paddle across the river for no other reason than the off chance there might be an eddy there - at the very least they'd get tired and at worst they'd risk end up encountering a dangerous river feature mid flow - whilst in the read and run simulation there is no penalty for constant clicking.

**Practice Effects**

The results show that not only does perceptual-cognitive performance fail to improve, but it actually drops over the course of the simulation. The significant increase in both eddies hit and eddies missed, suggests this may be as much to do with decreasing motivation as with a decrease in underlying skill.

This lack of improvement is unsurprising; Faubert & Sidebottom (2012) demonstrated improvement in performance within simulated perceptual-cognitive tasks over five (30 minute) sessions with hockey, rugby and football players whilst Put et al. (2015) showed improvement in the performance of football referees in simulated tasks over 12 sessions each of which involved 30 separate simulations (compared to just 1 session with 7 simulations in this study). This suggests that performance improvement over a sequence of perceptual-cognitive simulations is achievable, but not necessarily immediate which is in line with our findings. Hopwood et al. (2011) and Williams, Ward & Chapman (2003) demonstrated improved on-field, in-situ performance after taking part in programmes of simulated perceptual-cognitive skill tasks. However as Hadlow et al. (2018) point out, this is a very small evidence base on which to make generalised conclusions regarding how well simulation-based training transfers to the real world. As ever, more research is needed.

**On-line Simulation**

**Limitations.** The use of an open on-line simulation and the resultant ability of participants to self-select, poses a number of challenges. A traditional study using the novice-expert paradigm would have a bi-modal distribution of expertise across the combined groups (i.e. novices and experts, but no intermediates). In contrast, the approach taken in this study involves artificially binning a uni-modal distribution into different groups. At this point there is likely to be some departure from normality within the groups and perhaps also smaller between group differences. The sample has been arbitrarily divided for statistical and analytical reasons rather than into groups that might be expected to utilise different techniques to interpret their environment. In this study, participants may well be taken from a narrower spectrum of expertise than in other studies. Certainly there is a small cohort of extreme paddlers who are unlikely to have taken part in this study, who possess a skill level that is far in advance of most recreational paddlers. I would argue that this weakness is also a strength; this study has shown differences in perceptual-cognitive within a group that is truly representative of typical recreational paddlers.

The self-selection approach also means that it is impossible to choose the sample to control against pre-selected confounding variables and instead demands the use of statistical approaches to attempt to account for them.

In this case prior knowledge of the rapids proved to be a confounding variable, however this poses the question, what are we actually trying to measure? It is no surprise that prior knowledge of a rapid would allow the paddler to better anticipate eddies (if anything I was surprised at how small the effect proved to be), however is knowing that a there's large rock halfway down the rapid qualitatively different to knowing that a particular tennis player will tend to use their backhand shot close to the net? If we have paddled a rapid when the river is low and then return when the river is running at a higher level, does that count as prior knowledge? It is unclear if cleaving perceptual-cognitive skill into a generic and a rapid-specific component is either a theoretically useful or an ecologically valid thing to do.

Another limitation of web-based simulation is the necessity to rely on participants' own rating of their expertise. Baker, Côte & Deakin (2005) suggest selecting novice and expert groups to test based on *a priori* performance measures that are more than two standard deviations from the mean. However this requires an objective measurable performance outcome in a standardised repeatable environment which simply does not exist in recreational whitewater kayaking.

The variety of different devices used to take part is another possible source of variation. Spittle, Kremer & Hamilton (2010) found no correlation between screen size and performance in perceptual-cognitive simulations, however the variety of input methods – keyboard, mouse and touch-screen – provides another potentially confounding variable. Rogers et al. (2005) found that the effect of input device on performance was dependent on both the nature of the task and the age of the user,  whilst Roca et al. (2016) found greater differences between experts and novices when participants responded by moving rather than by pressing buttons. Travassos et al. (2013) in their meta-analysis of perceptual-cognitive expertise research in sport found that expertise had a similar effect on response time whether or not the participant was shown still images, video or was acting in their authentic performance environment and whether or not the participant was pushing buttons or actively engaged in their normal sporting activity. In contrast, significant differences were noted when response accuracy was measured, with much greater effect sizes for authentic performance compared to button clicking and for real life compared to video presentation. This would suggest that my simulation is likely to have underestimated the influence that expertise actually has on response accuracy (i.e. eddies hit and eddies missed) out on the water.

**Advantages.** As far as I am aware, web-based simulation has not previously been used as a research tool to study perceptual-cognitive expertise, although it has been used as a training tool (Put et al., 2015). Indeed this research required the development of two new pieces of software to display the simulation and to store, sort and process the results (see appendices 1 and 2). I would argue that online simulation has much to offer as a research tool in perceptual-cognitive research and more generally within the study of sports, movement and coaching. With most modern smartphones and tablets able to measure position, distance, timing, speed and acceleration, and able to capture sound,video and screen taps, 78% of adults and 95% of 16-24 year-olds (OFCOM, 2019) are now carrying a small sports science laboratory on their person.

Coupled with the ability to scale (Byrne, Heavey & Byrne, 2010)  (i.e. once the experiment is set up, it is no more work to capture 10000 participants' data than is to capture 10 ) I suggest that web-based simulation offers a opportunity to greatly increase the sample sizes traditionally used in sports coaching research, and perhaps enhance the statistical significance and power of their results.

This study has revealed statistically significant effects of expertise on all three performance variables measured, and 5 out of 6 novice-expert comparisons, with moderate to large effect sizes (when compared with the studies featured in Travassos et al.'s 2013 meta-analysis), that are in line with our initial hypotheses. That provides some evidence that online simulation can be used to provide an efficient, cost effective way to study perceptual-cognitive expertise. Using this approach to replicate an existing piece of research or better still running a trial in which both online simulation and traditional laboratory based simulation were used, would enable empirical comparisons to be made between the two approaches.

**Future directions.** Although not the approach taken in this study, in principle, the development of a continuous measure to describe expertise, coupled with a larger sample size, would lend itself to a regression analysis. Additionally the convenience of a web-based approach could make other study designs more practical. As Williams and Ericsson (2005) discuss, moving from the between group, cross-sectional design utilised in this study, to a longitudinal design would enable researchers to show not just that experts exhibit greater perceptual-cognitive skills than novices, but to investigate how the journey from novice to expert occurs.

The simulation of the inspect condition in which the participants are choosing their own eddies to hit prior to watching the video has been a unique feature of this research and an approach that I believe is representative of kayaking practice. To get the most out of this approach in the future I would want to randomise which rivers are seen under which conditions, to enable direct between condition comparisons to take place, and also to collect more data (either more participants or more river sections) under the inspect condition. I would also be in a better position to select the rapids, choosing those which are representative of UK kayaking but which also have clearly delineated, well spaced eddies to provide unambiguous results. Potentially other skill measures that go beyond identifying eddies could be developed. Adapting the software to give the participants a limited number of clicks might make the task more representative of real life paddling whilst also preventing the "click at anything" strategy that a small number of participants adopted. The increasing availability and ever decreasing price of 360 degree headcams would also enable the development of software which allows the user to choose in which direction they're looking. This information could also be logged and serve as an analogue of the eye-tracking information that has been used in other perceptual-cognitive research (Helsen & Starkes, 1999, Martell & Vickers, 2004, Reina, Moreno and Sanz, 2007). It would be possible to further develop the software into a more adaptable and user friendly product which would enable similar research to take place across multiple sports using different performance measures.

Finally it would be interesting to develop and investigate the efficacy of our online simulation as a training tool. The works of Armor & Sackett, (2006) and Hogarth, (2001) suggest that the provision of real time feedback of eddies hit and reaction times would make the simulation a better training tool; producing a product that might resemble a kayaking computer game more than a science experiment!

## Implications For Coaching

There is clear evidence that perceptual-cognitive skills are sport and environment specific (Drowatzky & Zuccato, 1967, Williams et al. 1993) and that measures of expertise do not transfer across the broad range of sports (Baker, Wattie & Schorer, 2017). The fact that more expert paddlers identify more eddies sooner than less expert paddlers might itself be more useful to a kayak coach than the inferred relationship between two theoretical constructs - expertise and perceptual-cognitive skill – that follow from the findings. I hope this result will help kayak coaches to justify and perhaps increase the emphasis they put upon helping their learners to understand the environment - identifying river features and anticipating how those features will affect their craft - rather than simply drilling technique.

In conclusion, this study has shown that under simulated conditions, more experienced paddlers who paddle more difficult rapids identify more eddies, more quickly than less experienced paddlers who paddler at lower grades. These results are consistent with statement that more expert kayakers demonstrate higher levels of perceptual–cognitive skill. The research findings are also consistent with belief that whitewater kayaking is as much a perceptual-cognitive as it is a physical endeavour. This research adds to the existing body of perceptual-cognitive expertise research and expands it into the realm of adventure sports. I also believe that this study demonstrates that web-based simulation has potential to be a useful tool in the study perceptual-cognitive expertise. An approach which offers the potential to garner larger sample sizes at lower cost than traditional laboratory based research.

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# Appendix 1 – Screenshots from simulation

## Introduction

Thanks very much for taking a look at this experiment. I'm studying how a whitewater paddler's ability and experience affect how they see a rapid. I want to know if more expert paddlers react faster and identify more attainable eddies, and whether we can **all** use web-based simulation to get better at this. This will involve collecting a bit of data about you – your age and how much boating you've done – and then I'm going to ask you to watch 8 short paddling videos, look at some pictures of rapids and click some buttons to identify eddies. The website will log how many eddies you identify and how quickly you spot them. The whole thing should take just over 5 minutes. I don't want to bore you, but if you want to learn more about what I'm trying to do then click here.

Your participation is entirely voluntary. If you decide that you don't want to take part then just close your browser window. If you want to find out more, have concerns or decide that you don't want your data used then email me at gef00018@students.stir.ac.uk. You can get hold of my supervisor at justine.allen@stir.ac.uk. Your anonymised data will be stored securely on my server and deleted 6 months after graduation (or 2 years after graduation if used in a published article) in accordance with university policy.

How old are you?

How many days did you spend paddling last year?

How many years have you been paddling?

What's the highest grade you normally paddle? 1

How familiar are you with the rapids we're going to use?

| | I've never paddled it | I've paddled it | I know it well |
|---|---|---|---|
| Findhorn, Dulsie Gorge | ● | ○ | ○ |
| Findhorn, Dragon's Teeth | ● | ○ | ○ |
| Findhorn, Elephant Rock | ● | ○ | ○ |
| Findhorn, Levens Gorge | ● | ○ | ○ |
| Leny, Falls of Leny | ● | ○ | ○ |
| Leny, S-bend | ● | ○ | ○ |
| Payette, Jacob's Ladder | ● | ○ | ○ |

By clicking this button I confirm I've understood all that and consent to the use of my data for research purposes. Next

## Video

We're about to pile on down a rapid.
As soon as you spot an eddy on the left, tap the"Left" button at the bottom of the video or tap the left arrow key on your keyboard. If it's on the right, click "Right" or press the right arrow key. Keep identifying new eddies until the video stops

Start Video

Left

Right

## Inspection

Thanks! This time we're going to inspect the rapid before we paddle it.
Click on the image to mark the eddies you're planning to hit with green dots. If you make a mistake there's no way to delete your selection , so please be careful!
Afterwards you'll see a video of the rapid and you'll try to spot your eddies from the water.


Next