An external focus of attention promotes flow experience during simulated driving

David J. Harris[1], Samuel J. Vine[1] and Mark R. Wilson[1]

[1]School of Sport and Health Sciences, University of Exeter, UK

Correspondence concerning this article should be addressed to David Harris or Mark Wilson, School of Sport and Health Sciences, University of Exeter, St. Luke's Campus Exeter EX1 2LU, UK. E-mail: D.J.Harris@exeter.ac.uk or Mark.Wilson@exeter.ac.uk

David Harris, Samuel Vine, and Mark Wilson declare that they have no conflicts of interest relevant to the content of this paper.

Acknowledgements – The authors would like to thank Gabriele Wulf for helpful discussions when designing this study.

Abstract

Achieving a state of flow is associated with positive experiences and improved sporting performance (Jackson & Csikszentmihalyi, 1999). Focused attention is a fundamental component of the flow experience, but to date there has been little investigation of whether attention plays a causal role in creating flow, or is a product of it. Consequently, this study aimed to test the effect of an attentional focus manipulation on flow and performance in a simulated driving task. It was predicted that an external focus would lead to improved visuomotor control, greater flow experience and improved performance. 33 participants from a student population completed the driving task under both internal and external focus instructions. Eye movements and steering wheel movements were recorded during each race. Participants reported greater flow experience (p<.001, *d*=1.78) and enhanced outcome expectancies (p=.02, *d*=0.41) under external, compared to internal focus conditions, however, there was no effect on visuomotor control (gaze-steering coordination and steering entropy) or racing performance (*p*s>0.28). These findings suggest that adopting an external focus of attention may contribute to positive performance states such as flow.

Keywords; the zone, attentional focus, eye tracking, peak performance, coordination, outcome expectancies

An external focus of attention promotes flow experience during simulated driving

Achieving an optimal mental state for peak performance is a primary goal for athletes. To demonstrate the skills developed through training, unencumbered by distracting or disruptive thoughts, athletes must find a facilitative level of arousal and focus their attention efficiently towards relevant elements of the task (Memmert, 2009). During the state of flow, or ‘the zone’, athletes report an intense task focus and complete absorption occurring with ease (Jackson & Csikszentmihalyi, 1999; Dietrich, 2004). Notably for performance psychologists, flow has been associated with improved sporting performance (Jackson & Csikszentmihalyi, 1999). Flow is linked with peak performances due to both athlete reports (Jackson, Thomas, Marsh, & Smethurst, 2001) and because of the beneficial cognitive features of flow (Dietrich, 2004). However, experimental approaches are yet to demonstrate a causal effect of flow on performance. Nonetheless an improved understanding of the cognitive mechanisms responsible for flow may enable people in sporting, work and leisure activities to achieve flow-like states more often, obtaining the associated motivation and performance benefits. Given the central role of attention in flow (Csikszentmihalyi, 1990), this study aimed to investigate the effect of an attentional focus manipulation for enhancing flow. Additionally, we aimed to further investigate how the psychological state of flow contributes to performance, through the potential contributory role of outcome expectancies.

Flow is often described in attentional terms, but researchers have only recently begun to examine the specific processes responsible (Harris, Vine & Wilson, 2017a; 2017b; Ulrich, Keller, & Grön 2016). Additionally, research to date has focused on changes *associated* with flow rather than *causally* responsible (Swann, Crust & Vella, 2017), limiting the ability to identify attention as a true mechanism. Therefore experimental approaches that control attention are needed to develop flow theory as well as practical applications. A fitting attentional manipulation may be to promote an external focus of attention. Focusing externally (on the movement effect), relative to internally (on bodily movements), has been found to provide substantial benefits for motor learning and performance (Wulf, McNevin & Shea, 2001; Wulf, 2013). The principal mechanism for the benefits of an external focus seems to be through enhanced motor automaticity (Kal, van der Kamp, & Houdijk, 2013; Wulf et al., 2001). For instance Kal et al. (2013) found reduced dual-task costs in a leg flexion task, and Wulf et al. (2001) found reduced probe reaction times in a balance task as a result of an external focus, indicating movements were not being executed through controlled processing. Similarly, McNevin, Shea and Wulf (2003) found more high frequency movement adjustments in a stabilometer task, suggesting that an external focus allowed performers to make use of self-organising capabilities of the motor system. As such, an external focus not only increases movement accuracy but also movement efficiency (Wulf, 2013). This type of smooth and efficient motor control is typical of athletes’ descriptions of flow (Jackson & Csikszentmihalyi, 1999).

Additionally an external focus avoids the disruptive effects of self-focus on the monitoring and control of movement mechanics (Beilock & Carr, 2001). Wulf and colleagues describe this through the ‘constrained action hypothesis’ (McNevin et al., 2003; Wulf et al., 2001); individuals who attempt to consciously control their movements may constraint their motor system, disrupting self-organising processes. Notably, Wulf and Lewthwaite (2010) link the self-schema system, activated through an internal focus, to the functional network of cortical mid-line structures which have also been found to be inactive during flow (Ulrich, Keller, Hoenig, Waller, & Grön, 2014; Ulrich et al., 2016). An external focus of attention may therefore further contribute to finding flow, through facilitating the reduction in self-consciousness found in flow states (Wulf & Lewthwaite, 2010).

There may also be an important overlap between the attentional focus and flow literatures, in terms of outcome expectancies. Within the OPTIMAL motor learning theory, Wulf and Lewthwaite (2016) outline how a range of predictive cognitions regarding future outcomes, referred to as *outcome expectancies*, may contribute to motor learning and motor performance. Enhanced outcome expectancies refer to positive beliefs about future outcomes including concepts such as self-efficacy, self-confidence and perceived competence. Enhanced expectancies are suggested to benefit movement through goal-action coupling – maintaining a focus on the task goal and away from the self. An external focus of attention similarly contributes to goal-action coupling, and hence performance, with better movement outcomes leading to enhanced self-efficacy expectations in a feedback loop.

Within the sporting literature, enhanced outcome expectancies, in particular self-confidence, have been associated with both flow (Swann, Keegan, Piggott, & Crust, 2012) and performance (McKay, Lewthwaite & Wulf, 2012). There are notable similarities between flow and enhanced expectancies regarding the role of challenge, and the relationship with focused attention (Bandura, 1993; Themanson & Rosen, 2015). Achieving an optimal balance between the challenge of the activity and the skill of the performer is a crucial determinant of flow (Csikszentmihalyi, 1990). Similarly, Bandura (1993) describes *mastery experiences,* which occur when individuals experience success in challenging tasks, as the most effective way of developing self-efficacy. Therefore, we would expect enhanced outcome expectancies during situations of optimal challenge, and a positive relationship between flow and outcome expectancies.

In summary, previous studies (Harris et al., 2017a; 2017b) have indicated an association between improved attention and flow, but research is yet to establish a causal direction. Therefore this study primarily aimed to assess the effect of instructions designed to create an internal or external focus of attention on flow and performance. Additionally, to further understand psychological processes that may contribute to the state of focused attention during flow, outcome expectancies were assessed in relation to flow and markers of visuomotor control. Additionally, as much attentional focus research has focused on relatively simple, discrete tasks, we aimed to extend this literature to a more complex visuo-motor skill. To this end, participants were given attentional focus instructions before completing a simulated driving task (as in Harris et al., 2017a). It was predicted, based on a range of previous work (Wulf, 2013; McNevin et al., 2003), that an external focus would promote improved performance, motor control and attention, and as a result, greater flow experience. Further, self-focus (on the hands during driving) has been shown to have negative performance consequences (Wilson, Stephenson, Chattington, & Marple-Horvat, 2007). Additionally it was predicted that enhanced outcome expectancies would further contribute to a state of flow, through a relationship with markers of attention control and performance.

Methods

Participants

Based on an a priori power analysis using G*Power (Faul, Erdfelder, Lang & Buchner, 2007), 33 participants were required in order to find a medium effect on self-reported flow (*d*=0.6, based on Harris et al., 2017a), to achieve a power of .90, given α=0.05. Therefore, 33 participants (16 female, mean age=22.6 *SD*=3.4) were recruited from undergraduate and postgraduate student populations through word of mouth. As the simulator controls were easy to learn, inclusion in the study did not require any previous real-world or simulated driving experience. Institutional ethical approval was acquired prior to recruitment, and participants gave written informed consent at the start of testing.

Apparatus

The simulated race used the game Forza 5 on the Xbox One (Microsoft), displayed through a Panasonic Viera 50inch HD flat-screen television. Participants sat in a Playseat Alcantra racing chair, fitted with a force-feedback Thrustmaster TX Ferrai 458 (Hillsboro, Oregon) racing wheel, accelerator and brake pedals. The screen was 120cm (approx.) from the participants' eyes. Steering wheel height and distance to the pedals was adjusted for each participant. A potentiometer, recording wheel movements in degrees of deviation from the 12 o'clock position at 60 Hz, was attached to the steering wheel column. The wheel recorded onto a Dell Inspiron Laptop positioned behind the participants' seat.

Participants' eye movements were recorded using SMI ETG 2.0 eye tracking glasses (SensoMotoric Instruments, Boston MA) that record onto a customised Samsung Galaxy smartphone. The glasses are lightweight (76 g) and record binocular eye movements to a spatial resolution of 0.5° at a rate of 60 Hz, allowing synchronisation with the steering wheel potentiometer. Participants had their head stabilised in a customised chin rest to eliminate head movement.

Measures

Manipulation check. To check for adherence to instructions participants indicated on a 1-10 scale the extent to which they were able to maintain the instructed focus, from '*1-Not at all'* to *'10-Completely'* (as in Wells & Papageorgiou, 1998).

Flow. State flow was measured using the Flow Short Scale (FSS; Rheinberg, Vollmeyer, & Engeser, 2003), a questionnaire used frequently in gaming research. 10 items such as '*I feel just the right amount of challenge'*, '*I have no difficulty concentrating'* and '*I am totally absorbed in what I am doing*' are rated for agreement on a 7-point Likert scale, with responses ranging from '*Very much'* to *'Not at all'.* The overall scale gave Cronbach's alpha = 0.88.

Outcome expectancies. As in Badami, VaezMousavi, Wulf and Namazizadeh (2011) enhanced expectancies were assessed using the perceived competence subscale of the intrinsic motivation inventory (IMI; McAuley, Duncan & Tammen, 1989). The items *'I think I am pretty good at this activity', 'I think I did pretty well at this activity compared to other students*' and '*This was an activity that I couldn't do very well*' (R) are rated on a 1-7 scale. These items gave Cronbach's alpha=.84.

Eye-steering coordination. To understand psychophysiological changes during flow, eye-steering coordination was used as a measure of visuomotor synchronization (see Figure 1). Gaze drives action in a variety of tasks, and directing visual attention to the cornering tangent point is crucial for negotiating bends during driving (Land & Lee, 1994), with the eyes moving to the apex of the corner around a second before the hands move the wheel (Yekshatayan & Lee, 2013). Highly coordinated gaze and wheel movements represent an optimal strategy (Chattington, Wilson, Ashford, & Marple-Horvat, 2007), with reduced coordination indicative of inattention (Yekshatyan & Lee, 2013). The coordination is assessed through identifying the optimal time lag between eyes and wheel, and the subsequent correlation between the two signals (*r*). A higher correlation between eye movements and hand movements indicates that gaze is more closely driving motor output (Chattington et al., 2007).

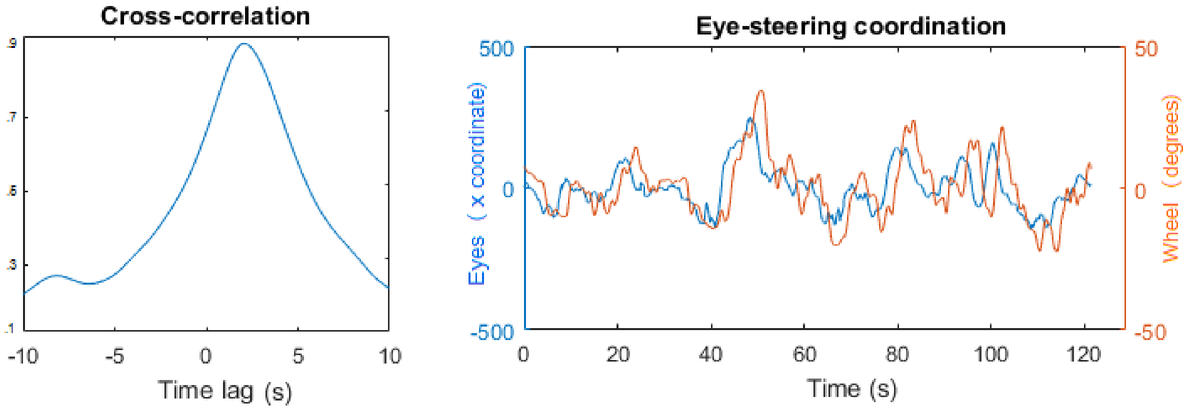

Figure 1. Eye-steering coordination for a single race. Panel A) (LHS) shows the peak correlation across time lags, Panel B) (RHS) shows superimposed gaze and wheel signals.

Steering entropy. To examine motor control, a measurement of steering wheel movement was obtained using a potentiometer. Sample entropy was used to assess the complexity of steering wheel movement. Entropy in general relates to rate of information production, and in a biological time series relates to randomness or complexity. Sample entropy is calculated from the natural logarithm of the conditional probability that a series similar for *n* points remains similar at the next point (see Richman & Moorman, 2000). Sample entropy is robust to variations in sample size. Measurements of higher entropy (in *bits*) would suggest a more complex steering strategy, most likely reflective of more corrective movements.

Procedure

Participants attended one testing session for approximately one hour. They first read the information sheet and had the experiment explained verbally before signing the consent form. Overall, participants completed 5 races (2 laps each) on the simulator. In each race, participants were required to complete two laps of a moderately difficult racecourse as a time trial (i.e. no opponents), with racing settings standardised across all races and participants. Three familiarization races were conducted, the first two without eye tracking equipment. Before the third race participants put on the SMI eye tracking glasses, and placed their head in the chin rest to allow familiarization with the equipment prior to the test races. Participants were then randomly assigned to either internal or external focus instructions in a counterbalanced design. Prior to the first test race the SMI eye tracking glasses were calibrated over three points across the television screen, and the tracking was then checked over a variety of markers across the screen.

Participants were next read instructions designed to promote either an internal or distal external focus. Internal focus: '*As you drive, keep your eyes on the road and maintain your focus on your hands on the steering wheel. This should help you steer more smoothly*.' External focus: '*As you drive, keep your eyes on the road and maintain your focus on where you are heading. This should help you become less distracted.* ' Instructions were designed to induce an internal/external focus, while still allowing the internal instructions to be task-relevant (cf. Collins, Carson, & Toner, 2016). A reminder of the focus of attention was given at the half-way point of each race (start of lap 2). Following each of the test races participants completed the Flow Short Scale and manipulation check questionnaires. At the end of testing, participants were debriefed and allowed to ask any questions regarding the study.

Data Analysis

Gaze data was downloaded from the SMI ETG to BeGaze 3.6 software for analysis, allowing raw csv data to be extracted from the gaze video. Gaze videos were checked for recording quality, with videos that displayed a poor calibration removed from the analysis (2 participants).

Data processing was conducted in Matlab (2016a). To compute time lag and cross-correlation in eye-steering coordination, x-axis gaze coordinates and wheel movements (in degrees) were time locked and filtered using a lowpass moving average filter. The cross-correlation function measures the degree of similarity across shifted sequences of the corresponding vector, as a function of the time lag. The peak lagged correlation indicates the average time lag between eyes and wheel, and *r* the degree of correlation between the signals. Sample entropy of the de-noised wheel signal was then calculated, using a tolerance of 0.2*standard deviation of the sample (Richman & Moorman, 2000).

Statistical analysis was performed using JASP (v0.7, Love et al., 2015). Dependent variables were analysed using paired t-tests to compare internal and external conditions, with Wilcoxon signed rank test used when data deviated from normality. Bayes Factors were also obtained using a symmetric Cauchy prior. We report BF_{10} which corresponds to the amount of evidence in favour of the alternative over the null model. We follow the convention that any $BF_{10} > 3$ is evidence for the alternative with factors of 10+ indicating strong evidence. Our raw data is available from the Open Science Framework [osf.io/y3fwj/].

Results

Manipulation check

Participants who reported a difficulty in maintaining the instructed attentional focus (scores of 3 or below on the manipulation check) were removed from the analysis (n=3).

A Mann-Whitney U one sample test indicated a preference for an external focus (M=7.82, SD=2.86, comparison value=6), $V(32)=304.00$, $p=.006$, $d=0.62$, $BF_{10}=18.25$.

Flow and outcome expectancies

Paired t-tests and Wilcoxon signed-rank tests were used to compare self-report scores between experimental conditions. There were significantly higher ratings of flow experience in the external condition ($M=46.88$, $SD=7.85$) than the internal condition ($M=32.91$, $SD=11.81$), $W(29)=525.50$, $p<.001$, $d=1.78$, $BF_{10}=6.72*10^8$ (Figure 2). Likewise there were significantly higher ratings of outcome expectancies in the external condition (M=12.41, SD=2.63) than the internal condition ($M=11.97$, $SD=3.51$), $t(28)=2.22$, $p=.04$, $d=0.41$, $BF_{10}=1.63$ (Figure 2).

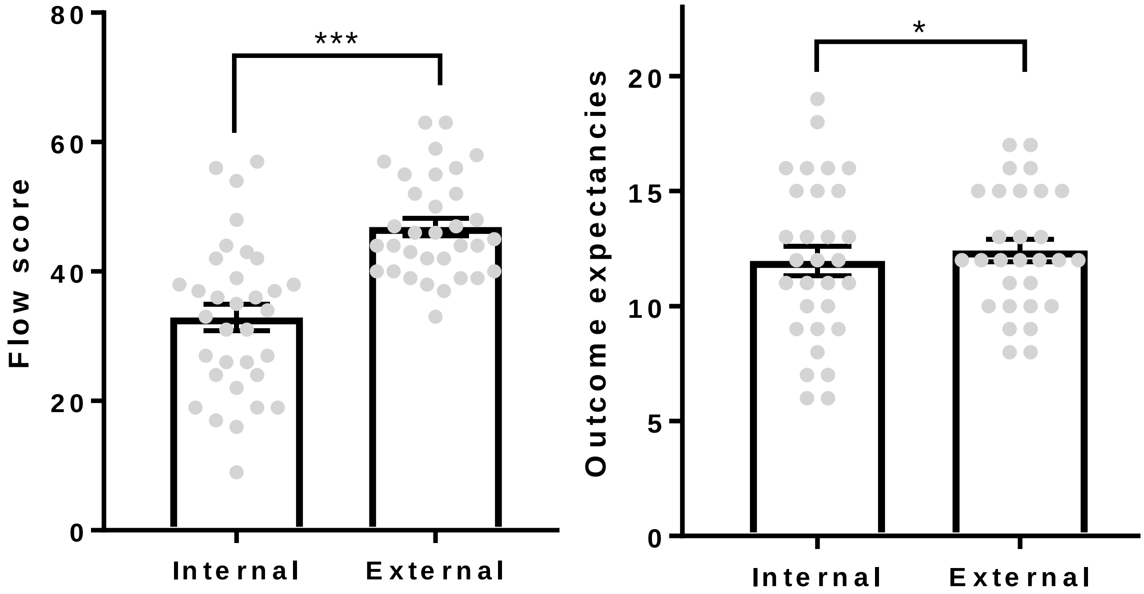

Figure 2. Group means (and standard error) of flow (LHS) and outcome expectancy scores (RHS). *p<.05, ***p<.001

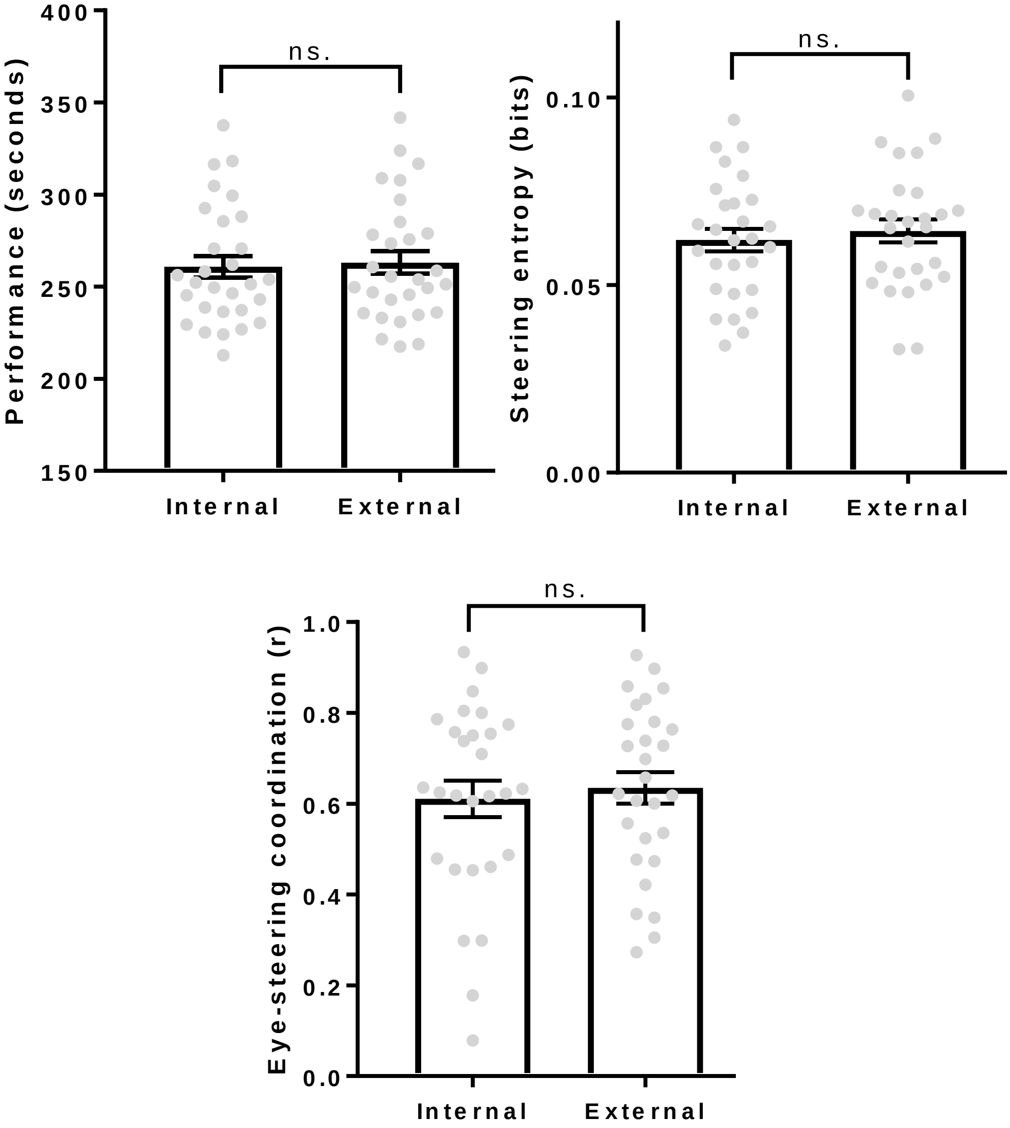

Figure 3. Group means (and standard error) of performance (Top-LHS), steering entropy (Top-RHS) and eye-steering coordination (Bottom). ns=non-significant

Performance measures

Paired t-tests indicated no difference in driving performance (seconds) between external (*M*=260.80 *SD*=32.17) and internal (*M*=254.40 *SD*=57.99) conditions, W(28)=249.00, *p*=.30, *d*=0.09, BF_{10}=0.22 (Figure 3). There was no difference in the degree of eye-steering correlation (*r*) between external (*M*=.64 *SD*=0.19) and internal conditions (*M*=.61 *SD*=0.21), *W*(27)=213.00, *p*=.83, *d*=0.12, BF_{10}=0.24 and no difference in time lag between external (*M*=1.28 *SD*=0.30) and internal conditions (*M*=1.26 *SD*=0.28), *t*(27)=0.28, *p*=.78, *d*=0.05, BF_{10}=0.21 (Figure 3). Similarly, there was no difference in steering wheel entropy between external (*M*=0.06, *SD*=0.02) and internal (*M*=0.06, *SD*=0.02) conditions, *t*(27)=-1.10, *p*=.28, *d*=0.21, BF_{10}=0.35 (Figure 3).

Correlations

Correlation analysis was used to examine the relationship between flow and other outcomes, across both conditions. There was found to be a significant relationship between flow and performance, *r*(62)=-.31, *p*=.01, BF_{10}=3.30, and flow and outcome expectancies, *r*(63)=.30, *p*=.02, BF_{10}=2.70.

Correlation analysis was also used to explore the relationship between outcome expectancies and performance markers. There was found to be a significant relationship between outcome expectancies and performance, *r*(63)=-.27, *p*=.03, BF_{10}=1.53. Outcome expectancies were also related to higher steering entropy, *r*(63)=.32, *p*=.01, BF_{10}=0.99, and improved eye-steering coordination, *r*(63)=.28, *p*=.03, BF_{10}=1.49 (Figure 4).

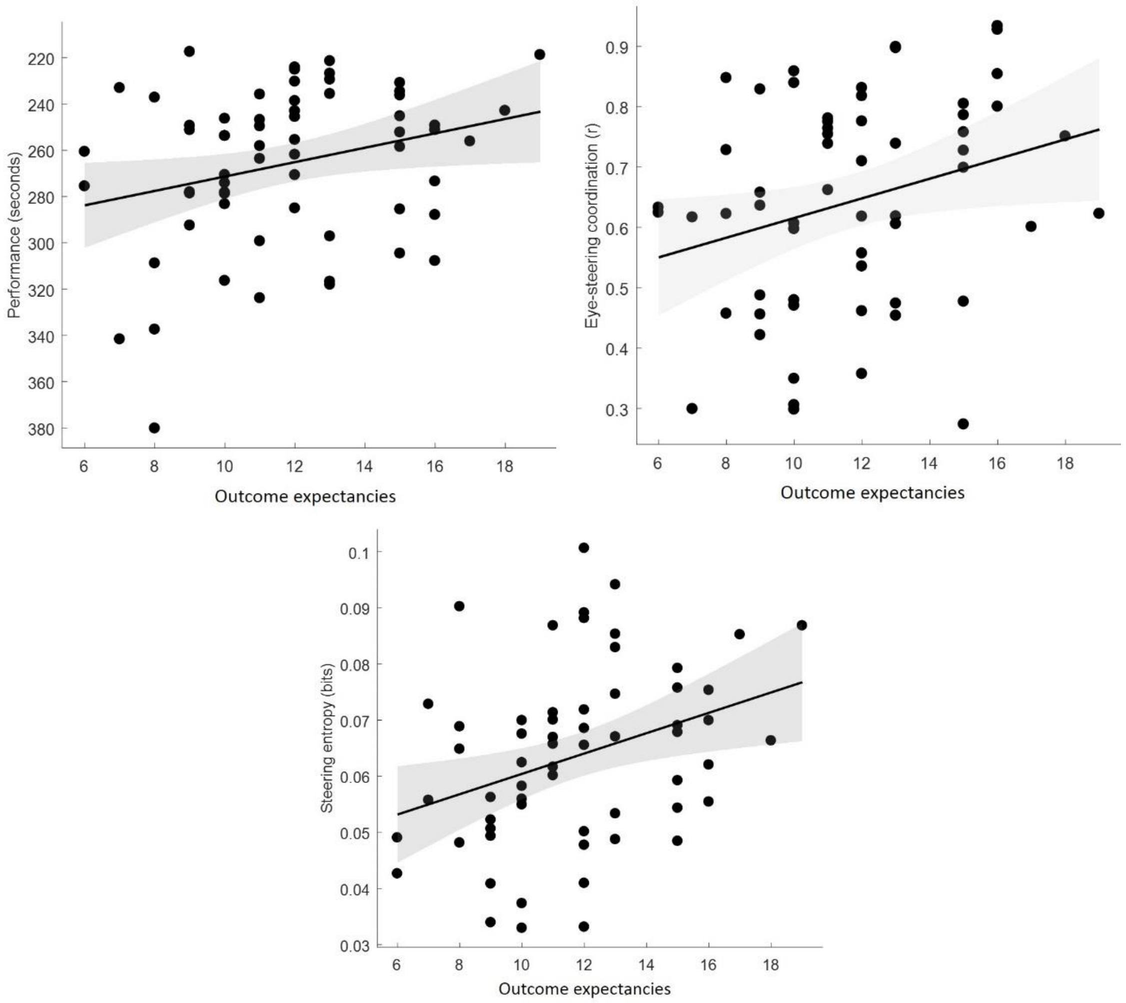

Figure 4. Relationship (with 95% CIS) between outcome expectancies and A) performance (r=.27, top left); B) eye-steering coordination (r=.28, top right); C) steering entropy (r=.32, bottom)

Discussion

Focused attention is described as a core component of the flow experience (Csikszentmihalyi, 1990), with recent neuroimaging and eye-tracking findings indicating that during flow, top-down attentional processes are strongly engaged (Ulrich et al., 2016; Harris et al., 2017a). Meanwhile, focus on the self may be inhibited (Ulrich et al., 2014). Experimental manipulations of attention are required to test whether attention changes are merely an outcome of flow, or have a causal effect. Additionally, simple manipulations of attention may provide practical applications for athletes to experience flow more frequently. Therefore this study sought to examine whether an attentional focus manipulation could facilitate flow experience in a simulated driving task.

In line with our primary hypothesis, external focus instructions lead to greater self-reported flow. This manifested as a large effect (*d*=1.78) indicating an appreciable difference, and Bayes Factor of >100, suggesting the data to be much more likely under the alternative hypothesis. This finding has implications for understanding the mechanisms behind flow as previous research has mostly *associated* attention changes with flow experience (Swann et al., 2017). The current finding however, points to a causal direction, that is, appropriate focusing of attention influences the experiential state. In general, work has indicated self-awareness to be disruptive for flow (Dietrich, 2004; Ulrich et al., 2016), although Jackson and Csikszentmihalyi (1999) describe the possibility of remaining highly self-aware during flow. The present findings are in line with a beneficial effect of focusing externally, rather than internally. If future research supports this causal effect of attentional focus, it may have important implications for theory and practice. Firstly, there is no convincing theoretical framework within the flow literature that describes the proximal causal mechanisms of flow. Dietrich’s (2004) hypofrontality theory could be considered such an approach, but recent findings are at odds with a state of hypofrontality (Harmat et al., 2015). A mechanism based on attention control may provide an alternative hypothesis. Following from this, if a causal influence of attention is supported it provides opportunities for applied interventions to promote flow.

The external attentional focus manipulation was also predicted to increase automated motor control (steering wheel entropy) and visuomotor coordination (eye-steering coordination), but this hypothesis was not supported (cf. Wulf, 2013). There were no significant group differences in these measures, with Bayes factors ranging from 0.23-0.35, suggesting weak support for the null. Similarly, there was no performance effect from instructions to focus externally, despite previous support in a range of tasks (Wulf, 2013). Consequently, we cannot conclude that visuomotor changes were responsible for increases in flow. The lack of a performance effect is potentially due to difficulties with the attentional focus manipulation, where participants were directed to the hands on the wheel (internal) or the direction of heading (external). However, they were also asked to maintain their gaze on the road, to avoid confounding the eye-movement analyses by cueing participants to look at their hands. This may have added an additional external element to both groups, reducing any effects of the manipulation. The driving task was also more complex than many used previously to investigate attentional focus (Wulf, 2013), hence future studies to confirm the effect of attentional focus on flow may wish to revert to more traditional balancing or throwing tasks.

It was also predicted that an external focus of attention would lead to enhanced outcome expectancies, based on the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). This prediction was marginally supported (p=.04) with a small to medium effect (d=0.41). A Bayes factor of 1.63, however, provides little support for the alternative hypothesis over the null. A difference in outcome expectancies is in line with the results of Pascua, Wulf and Lewthwaite (2015) who found external focus instructions to enhance self-efficacy in a tennis ball-throwing task, but only at a subsequent retention test. The OPTIMAL theory suggests that enhanced outcome expectancies and an external focus both benefit motor learning and performance, which in turn creates a feedback loop leading to further enhanced expectancies. As there was no evidence of performance improvement as a result of the manipulation, however, the effect of attentional focus on enhanced expectancies may have been through a more direct route, rather than feedback from performance.

A second group of predictions suggested that enhanced expectancies would be related to flow, performance and markers of attention and motor control, which were largely supported. Enhanced expectancies may be strongly tied to the *mastery experience* of challenge-skill balance in a task (Bandura, 1993), and has been linked to performance benefits through enhanced attention control (Themanson & Rosen, 2015). As a result, it may contribute to the state of focused performance during flow. In line with previous findings (Swann et al., 2012) there was a statistically significant, but relatively weak, relationship between flow experience and outcome expectancies, and between outcome expectancies and performance (McKay et al., 2012). Of greatest note were the relationships between outcome expectancies and eye-steering coordination and steering entropy. The degree of eye-steering coordination is a functional gaze-action coupling for negotiating corners (Chattington et al., 2007), which impairs performance when disrupted (Marple-Horvat et al., 2005), and indicates good attention during driving (Yekshatayan & Lee, 2013). Entropy in biological time series data is indicative of complexity or randomness (Richman & Moorman, 2000), and here may indicate smaller, more frequent, corrective movements characteristic of automated motor control, as has been found in frequency domain analyses of balance tasks (McNevin et al., 2003; Wulf et al., 2001). In combination, these measures indicate automated motor control and an improved functional coupling between gaze and action. It should be emphasised that these were fairly weak relationships (circa r=.30), but as a link between mere belief in outcome and precise measures of gaze-action coupling these results are nonetheless noteworthy. Overall, these findings indicate that outcome expectancies may indeed link to flow, performance and positive changes in attention and motor control.

In summary, the effect of attentional focus on flow experience found here suggests opportunities for finding flow in a variety of sporting, leisure and work settings. Within sport, even if an external focus of attention does not provide the established motor control benefits (Wulf, 2013), it may promote a positive experiential state (flow). Given the importance of goal directed attention in flow (Ulrich et al., 2016) techniques for long-term training of attentional abilities may enable more frequent flow experience. For instance computer-based attention training tasks may enhance executive abilities, although benefits tend to have limited generalisability (Tang & Posner, 2009). Alternatively, gaze training programmes like quiet eye training promote good visual attention control and an external focus (Moore, Vine, Cooke, Ring, & Wilson 2012), and can be implemented as a sport specific intervention. Quiet eye training may also contribute to enhanced outcome expectancies, as Wood and Wilson (2012) found a quiet eye trained group to not only improve their attention control in a soccer penalty task, but also showed increased perceptions of competence and reduced outcome uncertainty. While achieving flow on a regular basis may be unrealistic, such interventions may serve to regulate attention such that flow may become more common.

Conclusions

A growing body of research has revealed that the flow experience is underpinned by attention that is task-focused and directed away from the self (Ulrich et al., 2016). The current attentional focus manipulation elicited increased flow experience, showing attentional changes to have a causal effect on flow. Additionally, outcome expectancies were found to relate to both flow and improved visuomotor performance. Both the effect of the attentional focus instructions and the findings pertaining to outcome expectancies suggest practical benefits for finding flow through attention focusing and training techniques.

References

Badami, R., VaezMousavi, M., Wulf, G., & Namazizadeh, M. (2011). Feedback after good versus poor trials affects intrinsic motivation. *Research Quarterly for Exercise and Sport*, *82*(2), 360-364. Doi: 10.1080/02701367.2011.10599765

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educational Psychologist*, *28*(2), 117-148.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure?. *Journal of Experimental Psychology: General*, *130*(4), 701. Doi:10.1037%2F0096-3445.130.4.701

Chattington, M., Wilson, M., Ashford, D., & Marple-Horvat, D. E. (2007). Eye–steering coordination in natural driving. *Experimental Brain Research, 180*(1), 1-14. Doi:10.1007/s00221-006-0839-2

Collins, D., Carson, H. J., & Toner, J. (2016). Letter to the editor concerning the article "Performance of gymnastics skill benefits from an external focus of attention" by Abdollahipour, Wulf, Psotta & Nieto (2015). *Journal of Sports Sciences*, *34*(13), 1288-1292. Doi:10.1080/02640414.2015.1098782

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*. New York: Harper and Row.

Dietrich, A. (2004). Neurocognitive mechanisms underlying the experience of flow. *Consciousness and Cognition, 13*(4), 746-761. Doi:10.1016/j.concog.2004.07.002

Eysenck, M. W., & Wilson, M. R. (2016). *Sporting performance, pressure and cognition: introducing attentional control theory: sport. In D. Groome & M. Eysenck (2nd ed). An introduction to applied cognitive psychology. (pp. 329-350).* London: Routledge.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioural, and biomedical sciences. *Behaviour Research Methods, 39*(2), 175-191. Doi: 10.3758/BF03193146

Harmat, L., de Manzano, Ö., Theorell, T., Högman, L., Fischer, H., & Ullén, F. (2015). Physiological correlates of the flow experience during computer game playing. *International Journal of Psychophysiology*, *97*(1), 1-7. Doi:10.1016/j.ijpsycho.2015.05.001

Harris, D. J., Vine, S. J., & Wilson, M. R. (2017a). Is flow really effortless? The complex role of effortful attention. *Sport, Exercise, and Performance Psychology*, *6*(1), 103. Doi:10.1037/spy0000083

Harris, D. J., Vine, S. J., & Wilson, M. R. (2017b). Flow and quiet eye: the role of attentional control in flow experience. *Cognitive Processing*, 18(3) 343-347. Doi:10.1007/s10339-017-0794-9

Jackson, S. A., & Csikszentmihalyi, M. (1999). *Flow in Sports*. Champaign, IL: Human Kinetics.

Jackson, S. A., Thomas, P. R., Marsh, H. W., & Smethurst, C. J. (2001). Relationships between flow, self-concept, psychological skills, and performance. *Journal of Applied Sport Psychology, 13*(2), 129-153. Doi:10.1080/104132001753149865

Kal, E. C., Van der Kamp, J., & Houdijk, H. (2013). External attentional focus enhances movement automatization: A comprehensive test of the constrained action hypothesis. *Human Movement Science, 32*(4), 527-539. Doi:10.1016/j.humov.2013.04.001

Land, M. F., & Lee, D. N. (1994). Where do we look when we steer. *Nature, 369*, 742-744. Doi:10.1038/369742a0

Love, J., Selker, R., Marsman, M., Jamil, T., Dropmann, D., Verhagen, A. J., & Wagenmakers, E. J. (2015). JASP (Version 0.7) [computer software]. *Amsterdam, the Netherlands: Jasp project*.

Marple-Horvat, D. E., Chattington, M., Anglesea, M., Ashford, D. G., Wilson, M., & Keil, D. (2005). Prevention of coordinated eye movements and steering impairs driving performance. *Experimental Brain Research*, *163*(4), 411-420. Doi:10.1007/s00221-004-2192-7

McAuley, E., Duncan, T., & Tammen, V. V. (1989). Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: A confirmatory factor analysis. *Research Quarterly for Exercise and Sport*, *60*(1), 48-58. Doi:10.1080/02701367.1989.10607413

McKay, B., Lewthwaite, R., & Wulf, G. (2012). Enhanced expectancies improve performance under pressure. *Frontiers in Psychology*, *3*. Doi:10.3389/fpsyg.2012.00008

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, *67*(1), 22-29. Doi:10.1007/s00426-002-0093-6

Memmert, D. (2009). Pay attention! A review of visual attentional expertise in sport. *International Review of Sport and Exercise Psychology*, *2*(2), 119-138. Doi:10.1080/17509840802641372

Moore, L. J., Vine, S. J., Cooke, A., Ring, C., & Wilson, M. R. (2012). Quiet eye training expedites motor learning and aids performance under heightened anxiety: The roles of response programming and external attention. *Psychophysiology*, *49*(7), 1005-1015. Doi:10.1111/j.1469-8986.2012.01379.x

Pascua, L. A., Wulf, G., & Lewthwaite, R. (2015). Additive benefits of external focus and enhanced performance expectancy for motor learning. *Journal of Sports Sciences*, *33*(1), 58-66. Doi:10.1080/02640414.2014.922693

Rheinberg, F., Vollmeyer, R., & Engeser, S. (2003). Measuring flow experiences. In J. Stiensmeier-Pelster & F. Rheinberg (Eds.). *Diagnostik von Motivation und Selbstkonzept. Tests und Trends* (pp.261–279). Gottingen: Hogrefe. Doi:10.1007/s11031-008-9102-4

Richman, J. S., & Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *American Journal of Physiology-Heart and Circulatory Physiology*, *278*(6), H2039-H2049. Doi:10.1152/ajpheart.2000.278.6.H2039

Swann, C., Crust, L., & Vella, S. A. (2017). New directions in the psychology of optimal performance in sport: flow and clutch states. *Current Opinion in Psychology*, *16*, 48-53. Doi:10.1016/j.copsyc.2017.03.032

Swann, C., Keegan, R., Piggott, D., & Crust, L. (2012). A systematic review of the experience, occurrence, and controllability of flow states in elite sport. *Psychology of Sport and Exercise, 13*(6), 807-819. Doi:10.1016/j.psychsport.2012.05.006

Tang, Y. Y., & Posner, M. I. (2009). Attention training and attention state training. *Trends in Cognitive Sciences*, *13*(5), 222-227. Doi:10.1016/j.tics.2009.01.009

Themanson, J. R., & Rosen, P. J. (2015). Examining the relationships between self‐efficacy, task‐relevant attentional control, and task performance: Evidence from event‐related brain potentials. *British Journal of Psychology*, *106*(2), 253-271. Doi:10.1111/bjop.12091

Ulrich, M., Keller, J., & Grön, G. (2016). Dorsal Raphe Nucleus Down-Regulates Medial Prefrontal Cortex during Experience of Flow. *Frontiers in Behavioral Neuroscience*, *10*. Doi:10.3389/fnbeh.2016.00169

Ulrich, M., Keller, J., Hoenig, K., Waller, C., & Grön, G. (2014). Neural correlates of experimentally induced flow experiences. *Neuroimage, 86*, 194-202. Doi:10.1016/j.neuroimage.2013.08.019

Wells, A., & Papageorgiou, C. (1998). Social phobia: Effects of external attention on anxiety, negative beliefs, and perspective taking. *Behavior Therapy*, *29*(3), 357-370.

Wilson, M., Stephenson, S., Chattington, M., & Marple-Horvat, D. E. (2007). Eye movements coordinated with steering benefit performance even when vision is denied. *Experimental Brain Research*, *176*(3), 397-412. Doi:10.1007/s00221-006-0623-3

Wood, G., & Wilson, M. R. (2012). Quiet-eye training, perceived control and performing under pressure. *Psychology of Sport and Exercise*, *13*(6), 721-728. Doi:10.1016/j.psychsport.2012.05.003

Wulf, G. (2013). Attentional focus and motor learning: a review of 15 years. *International Review of Sport and Exercise Psychology*, *6*(1), 77-104. Doi:10.1080/1750984X.2012.723728

Wulf, G., & Lewthwaite, R. (2010). Effortless motor learning? An external focus of attention enhances movement effectiveness and efficiency. In B. Bruya (Ed.), *Effortless attention: A* *new perspective in the cognitive science of attention and action* (pp. 75-101). The MIT Press, Cambridge, MA.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382-1414. Doi:10.3758/s13423-015-0999-9

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology: Section A*, *54*(4), 1143-1154. Doi:10.1080/713756012

Yekhshatyan, L., & Lee, J. D. (2013). Changes in the correlation between eye and steering movements indicate driver distraction. *IEEE Transactions on Intelligent Transportation Systems*, *14*(1), 136-145. Doi:10.1109/TITS.2012.2208223