Examining the effect of state anxiety on compensatory and strategic adjustments in the planning of goal-directed aiming

James W. Roberts[a, b, c]

Mark R. Wilson[d], Jessica K. Skultety[b] & James L. Lyons[b],

[a]: University of Waterloo, School of Optometry & Vision Science,

200 Columbia Street West, Waterloo, ON, N2L 3G1, Canada

[b]: McMaster University, Department of Kinesiology,

1280 Main Street West, Hamilton, L8S 4L8, Canada

[c]: Liverpool Hope University, School of Health Sciences,

Hope Park, Liverpool, L16 9JD

[d]: University of Exeter, Sport and Health Sciences,

Heavitree Road, Exeter, EX1 2LU, UK

Corresponding author:

James W. Roberts

Liverpool Hope University

School of Health Sciences

Hope Park

Liverpool, UK

L16 9JD

This is an Accepted Manuscript of an article published by Elsevier in the Acta Psychologica on 19/01/2018, available online: http://dx.doi.org/10.1016/j.actpsy.2018.01.008

Abstract

The anxiety-perceptual-motor performance relationship may be enriched by investigations involving discrete manual responses due to the definitive demarcation of planning and control processes, which comprise the early and late portions of movement, respectively. To further examine the explanatory power of self-focus and distraction theories, we explored the potential of anxiety causing changes to movement planning that accommodate for anticipated negative effects in online control. As a result, we posed two hypotheses where anxiety causes performers to initially undershoot the target and enable more time to use visual feedback ('play-it-safe'), or fire a ballistic reach to cover a greater distance without later undertaking online control ('go-for-it'). Participants were tasked with an upper-limb movement to a single target under counter-balanced instructions to execute fast and accurate responses (low/normal anxiety) with non-contingent negative performance feedback (high anxiety). The results indicated that the previously identified negative impact of anxiety in online control was replicated. While anxiety caused a longer displacement to reach peak velocity and greater tendency to undershoot the target for the high compared to low anxiety, there appeared to be no shift in the attempts to utilise online visual feedback. Thus, the tendency to initially overshoot may manifest from an inefficient auxiliary procedure that manages to uphold overall movement time and response accuracy.

Key words: anxiety; self-focus theories; distraction theories; planning; online control

PsychINFO classification: 2330; 2340

Introduction

The effect that state anxiety (i.e., anxiety pertaining to a perceived threat within a particular situation) has on the performance of perceptual-motor tasks has attracted considerable research interest (see Eysenck & Wilson, 2016; Nieuwenhuys & Oudejans, 2012 for recent reviews). This interest is not surprising when we consider the large number of domains where individuals have to perform accurate movements under high-stress situations (e.g., medicine, aviation, military and sport). To date, the research findings have predominantly substantiated two select groups of anxiety theories: self-focus and distraction.

Self-focus theories (conscious processing hypothesis (CPH); Masters, 1992, explicit monitoring; Beilock & Carr, 2001) state that anxiety leads to attention being directed toward the performers' own movements, which may revert performance to an early-declarative stage of development (see Fitts & Posner, 1967) and/or elicit an internal focus-set that can heavily attenuate performance (see Wulf, McNevin & Shea, 2001). Alternatively, distraction theories (processing efficiency theory (PET); Eysenck & Calvo, 1992, attentional control theory (ACT); Eysenck et al., 2007) suggest anxiety can re-direct attention to irrelevant sources of worry, which may then compromise the availability of resources needed for processing task-relevant information. In this regard, performance effectiveness may be upheld by utilising auxiliary resources (e.g., mental effort), but at the expense of performance efficiency.

Recently, researchers have tried to understand more about anxiety and its related processes by exploring the specific effects it has on the planning and subsequent control of action (e.g., Allsop, Lawrence, Gray, & Khan, 2016; Causer, Holmes, Smith, & Williams, 2011; Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Lawrence, Khan & Hardy, 2013; Vine, Lee, Moore & Wilson, 2013). Most notably, Lawrence et al. (2013) posited an experimental design that directly examined distraction and self-focus theories by formulating opposing hypothetical outcomes within a single goal-directed movement. Adapted from the notion that manual goal-directed movements comprise two components – planning and control (Woodworth, 1899; see also Elliott, Helsen, & Chua, 2001); it was reasoned that distraction theories would allude to differences between high and low anxiety conditions during the planning phase of the movement, while self-focus theories would argue differences during the control phase of the movement. These competing sets of hypotheses assume that planning needs attention toward task-relevant information (e.g., target context), while control unfolds automatically with limited cognitive involvement. To infer planning and control processes, the researchers adopted a measure of spatial variability – dispersion of displacement at select kinematic landmarks (peak acceleration, peak velocity, peak deceleration, movement end) throughout the entire trajectory (see Figure 1). This measure is adapted from the notion that high-velocity long-amplitude movements naturally subtend greater amounts of variability compared to low-velocity short-amplitude movements (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; see also Meyer, Abrams, Kornblum, Wright, & Smith, 1988). Therefore, in an instance of a sudden decline in variability before the end of the movement, we can infer that an intervening control process was implemented and involved the use of online sensory feedback (Khan, Lawrence, Fourkas, et al., 2003; see also Khan et al., 2006). At the same time, any differences in variability between conditions that are captured during the early portions of the trajectory would reflect planning-related alterations, presumably with the aid of terminal feedback obtained from the previous trial (Khan, Lawrence, Franks, & Elliott, 2003). The results showed that there was greater spatial variability at the end of the movement for the high compared to low anxiety condition with no differences in the early portions of the movement. Thus, the findings offered strong support for the tenets of self-focus theories.

However, a follow-up study (Allsop et al., 2016) showed that while there was a similarly negative impact of high state anxiety in online control, there was also an impact observed within the early planning phase of the movement. Namely, there was lower spatial variability at peak acceleration, peak velocity and peak deceleration in the high compared to low anxiety condition. In addition, there was greater mental effort expended following the high anxiety condition. Hence, these findings seemed to reconcile the view of distraction theorists (e.g. Eysenck & Calvo, 1992), as there were changes made in the planning of the movement, while performance efficiency was compromised. As a result, the authors proposed that self-evoked auxiliary resources might have enabled some accommodation within pre-movement planning because of an anticipated deleterious effect of anxiety during late online control.

This conjecture is heavily adapted from recent developments to the two-component model of manual goal-directed movements (Elliott et al., 2010; Elliott et al., 2017). That is, while there are two dichotomous components, the anticipation of online sensory feedback can greatly inform the planning process so much so that online control is contingent upon the pre-planned use of sensory information. To elucidate, prior knowledge of visual feedback for goal-directed movements typically elicits a larger magnitude force and shorter proportional time at peak velocity (i.e., positive skew in the time-course of movement velocity) (Hansen, Glazebrook, Anson, Weeks, & Elliott, 2006; Khan, Elliott, Coull, Chua, & Lyons, 2002; see Causer, Hayes, Hooper, & Bennett, 2017 for an example of oculomotor control in golf-putting). What's more, a suspected decline in the ability to control can cause an increasingly shorter proportion of time to peak velocity (Mottet, van Dokkum, Froger, Gouïach, & Laffont, 2017; Timmis & Pardhan, 2012; Welsh, Higgins, & Elliott, 2007). That is, a further and faster reach within the early portions of the trajectory is presumably prepared to accommodate the late online control phase. In this regard, the forces and timing of goal-directed movements are parameterized with a view to utilising online sensory feedback. This view contends that performers must initially comprehend the sources of sensory information that they will receive late on in the movement.

Of interest, the planning of goal-directed movements is also contingent upon the potential outcome of movements (i.e., errors) and their implications for overall energy-expenditure (Elliott, Hansen, Mendoza, & Tremblay, 2004). As a result, the limb will typically fall short of the target prior to undertaking late online control because it avoids an overshoot error that requires more time and energy to amend (Lyons, Hansen, Hurding, & Elliott, 2006; Roberts, Elliott, Burkitt, & Lyons, 2016; cf. Roberts, Blinch et al., 2016). Corrections to an initial overshoot require performers to reverse the limb, which contend with the more demanding situation of overcoming inertia and alternating agonist and antagonistic muscle functions. Hence, it is in the performers' best interest to 'play-it-safe' and initially undershoot the target if indeed they are to potentially miss and assume a late correction. Because of this particular feature in planning, it stands to reason that in situations of greater uncertainty there will be a more conservative means to avoid an undesirable movement outcome – the more uncertain the outcome, the greater the undershoot. Indeed, it has been shown that unintended spatial variability negatively co-varies with the extent of the primary movement amplitude (Worringham, 1991; see also Harris & Wolpert, 1998).

However, a feasible alternative may be offered by Allsop et al. (2016) who indicated that performers may contest the negative effects in online control by inversely limiting the need to amend the limb following an initial restriction to the spatial variability. In a similar vein, Cassell and colleagues (Cassell, Beattie, & Lawrence, 2017) found that the prolonged movement times from practice with anxiety to transfer with no anxiety (control) failed to unfold in the reverse context (i.e., no anxiety-practice to anxiety-transfer). Indeed, the absence of a negative specificity effect when transferring to a situation of anxiety was suggested to result from performers opting for an open-loop approach where extending the time for visually-regulated online control served no added benefit. Taken together, it may be conceived that the performer seeks to 'go-for-it' by way of a pre-planned arrangement to limit the variability and increase the chances of landing inside the target without the guidance of online visual feedback. Therefore, a high-stress situation may be likened to an approach typically adopted in open-loop/no vision conditions – trajectory modifications being isolated to the early movement phases without concern or accommodation for visually-regulated online corrections. While this approach may seem counter-intuitive due to a failure to take advantage of the visual feedback that is available, it is still very much a possibility if the performer assumes online control serves no further advantage to an already refined initial impulse.

The aim of the present study was to more closely examine the planning and control of goal-directed aiming movements under high and low state anxiety. More specifically, we aim to re-examine the indices that are traditionally adopted to indicate planning and control (i.e., spatio-temporal dynamics of peak acceleration, peak velocity, peak deceleration and movement end). As per previous findings (Allsop et al., 2016; Lawrence et al., 2013), it is predicted that there will be an increase in variability at the end of the movement, which will be partially offset by a decrease earlier in the movement (peak acceleration/peak velocity/peak deceleration) for the high compared to low anxiety condition. The subsequent analyses therein may be leveraged to elucidate the precise source of these pre-planned modifications. Indeed, the traditional perspective of optimizing the utilisation of visual feedback and energy-expenditure (*play-it-safe strategy*; Elliott et al., 2004) predicts that there will be a strategic shift in the use of online visual feedback as indicated by a shorter proportion of time to reach peak velocity – extending the time after peak velocity – for the high compared to low anxiety condition. What's more, the uncertainty surrounding movement outcomes should drive a shorter primary movement and/or increase the frequency of undershoots for the high compared to low anxiety condition. Alternatively, the predominantly feedforward control perspective (*go-for-it strategy*) assumes that anxiety will invoke an inverse extension to the proportion of time to peak velocity (resembling a more symmetric velocity profile) (Hansen et al., 2006; Khan et al. 2002), increase the displacement at the primary movement (Khan, Franks, & Goodman, 1998), and decrease the frequency of two-component submovements (Elliott et al., 2014). Finally, the more extreme version of this approach may render a trade-off between speed and accuracy, where time-consuming visual feedback-based corrections may be eradicated at the expense of a larger error rate for the high compared to low anxiety condition (see Carlton, 1981; Elliott & Madalena, 1987; Khan et al., 1998).

[Insert Figure 1 about here]

Method

Participants

Fourteen participants, with an age range of 18-30 years, took part in the study. All participants were self-reported right handed, had normal or corrected-to-normal vision and no neurological and/or anxiety disorders. The study was designed and conducted in accordance with the Declaration of Helsinki, and was approved by the McMaster Research Ethics Board.

Apparatus and Materials

The stimulus was displayed on a 57 cm x 34 cm computer monitor with a temporal resolution of 60 Hz and spatial resolution of 1024 x 768 pixels. An in-house designed open-faced frame was used to secure the monitor (see Roberts, Burkitt et al., 2016). The frame was held in-place by an adjustable steel ledge (43.0 cm x 35.5 cm), which was attached to a vertical stand (180 cm height). The ledge and affixed frame were oriented horizontally so the monitor display was directly facing up, while the height was adjusted to the hip joint of the participant. An infra-red marker was attached to the tip of the right index finger and detected via an Optotrak 3020 (Northern Digital Instruments, Waterloo, ON) collecting at 200 Hz for a period of 2 s. A custom-written program in E-prime (Psychology Software Tools Inc., Sharpsburg, PA) was used to control the stimulus and trigger the Optotrak via a parallel port connection.

State anxiety was measured using the Mental Readiness Form-3 (MRF-3) (Krane, 1994), which features three bipolar 11-point subscales that indicate cognitive anxiety (not worried-worried), somatic anxiety (not tense-tense) and self-confidence (confident-not confident). In a similar vein to previous studies (e.g., Lawrence et al., 2013; Wilson, Chattington, Marple-Horvat, & Smith, 2007), we focused on the cognitive anxiety subscale.

Task and Procedure

Participants were instructed to aim their right index finger toward a circular target as fast and accurately as possible. The target and movement parameters were adapted from Lawrence et al. (2013). That is, the home position and target object were 1 cm in diameter and separated by 24 cm (centre-to-centre). Both the home position and target object were coloured black and appeared on a white background. Individual trials proceeded with the appearance of the home position near the midline of the participant. Following a random foreperiod (800-2800 ms; 500 ms intervals), the target would appear along the midline and cued the participant to move. Each participant was provided a familiarisation period of 30 trials involving the execution of movements as fast and accurate as possible. The participant then completed a total of 60 experimental trials, which were separated into two blocks of 30 trials. Prior to each block, the participant was provided an instructional set that was specifically designed to manipulate state anxiety.

For the high anxiety condition, the experimenter instructed the participant to take a break while their data was being assessed. This pretence featured the experimenter visibly transferring the electronic movement trial files from the Optotrak computer to a separate lab computer. The experimenter would then look at the computer and pretend to perform a series of functions in order to assess the data. After a three-minute delay, the experimenter would turn to the participant and inform them that an index of their performance, which computationally combines their speed and accuracy, was calculated and revealed that their performance entered into the lower 30th percentile out of all the participants previously collected. In addition, the participant was instructed that if they were to move up in the rankings then they would have to execute faster and more accurate responses. This anxiety manipulation follows a similar procedure to previous studies that have raised ego-threat through the provision of non-contingent performance feedback (e.g., Wilson, Vine, & Wood, 2009). For the low anxiety condition, the experimenter simply instructed the participant to keep executing fast and accurate responses. While false performance feedback may not be ideal because of the potential to contaminate movement performance independent of felt stress (Cassell et al., 2017), it is important to realise that the instructions equally emphasised the importance of both accuracy and speed – failure in either or both would cause a poorer performance evaluation. As a result, the instructions were unlikely to cause a trade-off between speed and accuracy, and thus rendered the same performance objectives as the low anxiety/control condition

Because familiarisation/practice at a goal-directed aiming task can strongly mediate the planning and control of actions (Elliott et al., 2004), both sets of instructions were received in a counter-balanced order. Therefore, in the event the high condition was received first then the participant was led to believe that the performance evaluation and non-contingent feedback was based solely on the initial practice trials (i.e., first 30 trials). However, if the high condition was received last then the participant was led to believe that the performance evaluation and non-contingent feedback was based on the practice and low anxiety trials (i.e., total of 60 trials). In the event the low condition was received first then the participant was led to believe that they were continuing to move as fast and accurately as possible without their performance being assessed. If the low condition was received last then the participant was led to believe that the upcoming trials made up the penultimate block where performance was not being assessed. Finally, each participant completed the MRF-3 prior to and mid-way between each individual block of experimental movement trials.

Data Reduction and Dependent Measures

Position data were filtered using a second-order, dual-pass Butterworth filter with a 10Hz low-pass cut-off frequency. Data were differentiated and double-differentiated to obtain velocity and acceleration, respectively. Movement onset and offset were defined as the first frame where the velocity reached respectively above and below 10mm/s in the primary axis of the movement (z-axis) for a period of at least 40ms (8 frames). The primary axis was selected because it more appropriately reflects the empirical works of movement optimization (e.g., Elliott et al., 2004; Lyons et al., 2006) for which our hypotheses have been heavily adapted.

Secondly, the nature of the task encompasses the planning and control of the movement amplitude, which isolates potential influences to the primary direction (Khan & Binsted, 2010; see also Gordon, Ghilardi, & Ghez, 1994), including the motion and position of the limb (Elliott et al., 2010).

Performance outcomes: We initially assessed coarse indicators of performance using the outcome variables of reaction time, movement time, proportion of target errors (categorised by absolute endpoint location relative to target-centre (% of total trials); < -5 mm or > 5 mm), constant error (signed error differences between the participant movement end and the target location with negative scores indicating an undershoot) and variable error (population standard deviation of the signed error differences).

Movement kinematics: Using a custom-written program in MATLAB (The Mathworks, Inc.), we identified the moment of peak acceleration, peak velocity and peak deceleration within each of the movement trials and calculated their time, displacement and magnitude. Because the prior knowledge of sensory feedback for upcoming trials can lead to a strategic shift in the proportional time dedicated to online control (see Hansen et al., 2006), we also calculated the proportion of time to peak velocity. Additionally, based on the notion that reverses in variability following increasing amplitude indicate an intervening control process (Khan et al., 2006), and in keeping with previous studies (Allsop et al., 2016; Lawrence et al., 2013), we assessed the within-participant standard deviation of the displacement for each of the kinematic landmarks.

Component submovements: Trials featuring two-component submovements were identified by marking the end of the primary submovement, which could be indicated by a positive-to-negative zero-line crossing in velocity (synonymous with a movement reversal), a negative-to-positive zero-line crossing in acceleration (synonymous with a re-acceleration) and/or deviation in the acceleration trace following peak velocity (synonymous with discontinuities or ‘braking’) (see Khan et al., 2006 for more detail). Thereafter, the mean and within-participant standard deviation of the primary movement endpoint was calculated, as well as the frequency of primary movement outcomes with respect to the target. More precisely, primary movements were categorised by whether they landed under (< -5 mm), on (> -5 mm and < +5 mm) or over (> +5 mm) the target-centre.

Data Analysis

In order to check our manipulation and ensure that the high anxiety condition generated greater cognitive state anxiety than the low anxiety condition, we first compared the mean MRF-3 scores between the high and low anxiety conditions. Because Likert scale data assume an ordinal level scale, the non-parametric Wilcoxon signed-rank test (one-tailed) was adopted for this particular comparison (see Jamieson, 2004 and Roberts, Bennett, Elliott, & Hayes, 2016).

For the analysis of performance outcomes and mean movement kinematics (peak acceleration, peak velocity, peak deceleration, movement end), we used paired-samples dependent t-tests to compare the high and low anxiety conditions. Because spatial variability assumes a progressive increase across movement amplitude prior to a control-based intervention, we analysed this by using a 2 Anxiety (high, low) x 4 Kinematic landmark (PA, PV, PD, END) repeated-measures ANOVA. For the analysis of component submovements, we again used paired-samples t-tests for the mean displacement and spatial variability at the primary movement. The outcome of primary movements were analysed using a 2 Anxiety (high, low) x 3 Outcome (under, on, over) repeated-measures ANOVA. For each of the omnibus ANOVAs, we corrected any violations in the Sphericity-assumption (as indicated by Mauchly's test of Sphericity; $p < .05$) by using the Huynh-Feldt correction when ε was greater than or equal to .75, or the Greenhouse-Geisser correction if otherwise (original Sphericity-assumed degrees of freedom were reported). Significant main or interaction effects featuring more than two means were decomposed using the Tukey HSD post hoc procedure. For all statistical analyses, significance was declared at $p < .05$.

Results

Eleven of the fourteen participants were forwarded to the analysis having successfully reported believing the non-contingent feedback and the related instruction of a decline in speed and accuracy. The initial manipulation check confirmed that the high anxiety condition generated significantly greater cognitive state anxiety than the low anxiety condition ($T = 1.5$, $z = -1.90$, $p < .05$) (see Table 1).

Any trials that were performed with a reaction time <100 ms or >1000 ms were deemed to be anticipatory and non-reactive responses, respectively. Movement times that exceeded

800 ms were considered not to be rapid goal-directed responses (e.g., Lawrence, Khan, Mottram, Adam, & Buckolz, 2016). On each of these occasions then the entire trial was removed before data analysis.

Performance Outcomes

Table 1 shows the mean performance outcomes. Indeed, there were no significant differences between the high and low anxiety condition for proportion of target errors ($t(10) = 1.56$, $p > .05$, $d = .47$), and constant error ($t(10) = 1.11$, $p > .05$, $d = .33$). The differences between the high and low anxiety conditions failed to reach conventional levels of significance for reaction time ($t(10) = 1.91$, $p = .085$, $d = .58$), and movement time ($t(10) = 2.08$, $p = .064$, $d =.63$), although tended to indicate that high anxiety trials were initiated earlier and executed faster than low anxiety trials. Meanwhile, there was a significant difference in variable error ($t(10) = 3.16$, $p < .05$, $d = .95$) with a larger dispersion subtended by the high compared to low anxiety condition.

[Insert Table 1 about here]

Movement Kinematics

Table 2 shows the mean kinematic variables. For the time to kinematic landmarks, there were no significant differences at peak acceleration ($t(10) = .80$, $p > .05$, $d = .24$) and peak velocity ($t(10) = .55$, $p > .05$, $d = .17$). There was a significant difference for the time to peak deceleration ($t(10) = 2.27$, $p < .05$, $d = .68$) with a shorter time for the high compared to the low anxiety condition. There were no significant differences in the proportion of time to peak velocity ($t(10) = 1.68$, $p > .05$, $d = .51$).

The displacement at kinematic landmarks revealed no significant difference at peak acceleration ($t(10) = 1.28$, $p > .05$, $d = .39$), peak deceleration ($t(10) = .17$, $p > .05$, $d = .05$), and the end of the movement ($t(10) = 1.58$, $p > .05$, $d = .48$). There was a significant difference for the displacement at peak velocity ($t(10) = 2.72$, $p < .05$, $d = .82$) indicating a longer displacement for the high compared to the low anxiety condition. Meanwhile, the magnitude of kinematic landmarks revealed no significant difference at peak acceleration ($t(10) = .99$, $p > .05$, *d* = .30), while the differences at peak velocity ($t(10) = 2.16$, $p = .056$, $d = .65$) and peak deceleration ($t(10) = 2.04$, $p = .069$, $d = .62$), neared conventional levels of significance, with a greater magnitude following the high compared to the low anxiety condition.

The spatial variability analysis revealed no significant main effect of anxiety ($F(1, 10) = 2.25$, $p > .05$, *partial* $\eta^2 = .18$), although there was a significant main effect of kinematic landmark ($F(3, 30) = 32.68$, $p < .05$, *partial* $\eta^2 = .77$) indicating a progressive increase from peak acceleration to peak deceleration prior to a decrease at movement end. Of even greater interest, there was a significant Anxiety x Kinematic landmark interaction ($F(3, 30) = 3.00$, $p < .05$, *partial* $\eta^2 = .23$) (see Figure 2). Post hoc analyses revealed that while there were no significant differences at peak acceleration, peak velocity and movement end (*ps* > .05), there was significantly lower spatial variability at peak deceleration for the high compared to the low anxiety condition ($p < .05$).

[Insert Table 2 and Figure 2 about here]

Component submovements

Table 3 indicates measures at the primary movement endpoint. There was no significant difference between the high and low anxiety conditions for the proportion of two-component submovements (i.e., consisting of both primary and secondary submovements) ($t(10) = .16$, $p > .05$, $d = .05$). There were no significant differences for the mean displacement ($t(10) = .99$, $p > .05$, $d = .30$), nor spatial variability ($t(10) = .05$, $p > .05$, $d = .02$) of the primary movement.

There was no significant main effect of anxiety ($F(1, 10) = 1.00$, $p > .05$, *partial* $\eta^2 = .09$), although there was a significant main effect of outcome ($F(2, 20) = 28.98$, $p < .05$, *partial* $\eta^2 = .74$) indicating a larger number of target hits compared to undershoots and overshoots, which failed to differ from each other. This effect was superseded by a significant Anxiety x Outcome interaction ($F(2, 20) = 3.57$, $p < .05$, *partial* $\eta^2 = .26$). Post hoc analyses revealed that there were no significant differences between anxiety conditions for the number of undershoots and target hits (*ps* > .05), although there was a greater number of overshoots for the high compared to the low anxiety condition ($p < .05$).

In order to assess the implications of primary movement outcomes on performance, we examined the mean movement times following select categories of primary movement outcomes. That is, we compared the movement times following primary movement undershoots, direct hits and overshoots (see Elliott et al., 2004).[1] There was no significant main effect of anxiety ($F(1, 9) = 2.42$, $p > .05$, *partial* $\eta^2 = .16$), although there was a significant main effect of outcome ($F(2, 18) = 8.59$, $p < .05$, *partial* $\eta^2 = .49$) indicating a longer time for overshoots (M = 481.72 ms, SE = 4.89) compared to target hits (M = 436.17 ms, SE = 5.21) with an intermediate time for undershoots (M = 469.36 ms, SE = 5.92). There was no significant Anxiety x Outcome interaction ($F(2, 18) = 1.45$, $p > .05$, *partial* $\eta^2 = .26$).

[Insert Table 2 about here]

Supplementary analyses – Online control

Because the magnitude of differences in variable error may be considered meagre (mean difference = .48), we sought further clarification of the deleterious effect of anxiety within online control. Based on the notion that accurate endpoint responses require a compensation of the distances travelled to kinematic landmarks by adjusting the distances travelled after them, it is reasonable to assume that there will be a stronger negative relation between the displacements to and after kinematic landmarks in the event of a more proficient online control process (Elliott, Binsted, & Heath, 1999; Khan, Sarteep, Mottram, Lawrence, & Adam, 2011; Roberts, Elliott, Lyons, Hayes, & Bennett, 2016). Therefore, we calculated within-participant correlations between the displacements to and after kinematic landmarks followed by a Fisher z-transformation. A paired-samples t-test revealed that a significantly smaller negative relation at peak deceleration began to emerge for the high (M = -2.14, SE = .14) compared to low (M = -2.42, SE = .11) anxiety condition ($t(10) = 3.29$, $p < .05$, $d = .97$). Thus, there was confirmation of a negative impact of anxiety during online control.

Summary

The results summarised herein will be referred to in the context of the effect served by high state anxiety as opposed to low/normal state anxiety: There was an increase in variable error at the end of the movement, which was corroborated by a smaller relation between the distances travelled to and after peak deceleration. These effects within online control were preceded by an extended displacement at peak velocity, and reduced time and spatial variability at peak deceleration. At the same time, there was no strategic shift in the proportion of time to reach peak velocity, which indicates a limited change in the time designated to offline planning and online control. Finally, there appeared no evidence of a shortening of the amplitude displacement of primary movement endpoints. Instead, there was a marginally greater proportion of primary movements that overshot the target location.

Discussion

Previous research has suggested that our understanding of the anxiety-perceptual-motor performance relationship can be greatly informed by the type of goal-directed aiming paradigm used in the current study (e.g., Lawrence et al., 2013). Indeed, this paradigm provides the opportunity to demarcate both the planning and control phases and elucidates the precise sensorimotor processes underlying the effect of anxiety. That is, the early planning phase comprises features that require attention to task-relevant information that could become compromised when anxious (distraction hypothesis). Alternatively, the late control phase, which typically features limited cognitive involvement, may become cognitively decomposed or explicitly attended to when anxious (self-focus hypothesis).

Previously, it was suggested that the potential negative influence of anxiety within online control (Lawrence et al., 2013) might be compensated within pre-movement planning (Allsop et al., 2016). Thus, the present study predicted that high anxiety will inflict increases in endpoint variability, which would be partially offset by a decrease during the earlier portions of the movement (peak acceleration/peak velocity/peak deceleration). In keeping with the view of movement optimization or the *play-it-safe strategy* (Elliott et al., 2004; Elliott et al., 2010), the anticipation of upcoming sensory information assumes that an attenuation in control caused by high anxiety should subsequently extend the time spent after peak velocity (shorter proportion of time to peak velocity) (Hansen et al., 2006; Khan et al., 2002; Welsh et al., 2007). In addition, the growing uncertainty surrounding potential movement outcomes following high anxiety should generate a more profound tendency to undershoot the target in order to avoid time- and energy-consuming corrections (Elliott et al., 2004). Alternatively, the pure feedforward or *go-for-it strategy* (Allsop et al., 2016), where planning-related modifications fail to incorporate the possibility of utilising online visual feedback, assumes a similar pattern of results as a standard no vision condition. That is, there should be a longer proportion of time to peak velocity, extended displacement at the primary movement, reduced propensity for two-component submovements, and possibly more errors for the high compared to low anxiety condition.

In agreement with our first hypothesis, there was an increase in variability toward the end of the movement (see VE effects) combined with decreases at peak deceleration for the high compared to low anxiety condition.[2] These findings partially replicate those of Allsop et al. (2016), and thus correspond with suggestions of accommodation within the planning phase. That is, the anticipation of a limited control process means performers must attempt to compensate by restricting the amount of variability accumulated within the earlier portions of the movement. Consistent with this conjecture was evidence of a longer displacement at peak velocity, and shorter onset and more abrupt peak deceleration for the high compared to low anxiety condition.

The accommodation demonstrated in planning following high anxiety failed to extend to differences in the proportion of time to peak velocity. Indeed, a measure of the relative time-course of velocity can allude to the amount of online control within a single goal-directed movement (e.g., Chua & Elliott, 1993; Elliott, Pollock, Lyons, & Chua, 1995). The typical response in the presence of visual feedback combined with the knowledge of a deleterious effect in online control is to distribute more time after peak velocity. In contrast, the much riskier measure (i.e., more likely to incur a speed-accuracy trade-off) of the performer eradicating the temporal delay of visually-regulated online control should manifest in an extended proportion of time to peak velocity. However, the limited differences found in the present study may suggest that despite the attenuation to online control following high state anxiety, there were no strategic adjustments in the time dedicated to sensory feedback processing. We suspect the failure to strategically shift the time dedicated to online control may be because participants were trying to uphold short overall performance or movement times (visual feedback delay >100 ms; Carlton, 1992), while still ensuring a relatively precise endpoint target response.

In a similar vein, there were limited differences in the displacement of the primary movements. This finding may be somewhat surprising given the differences in endpoint variability and the fact standard goal-directed responses involve an inverse relation between the primary movement endpoints and the degree of uncertainty surrounding initial movement outcomes (Lyons et al., 2006; Worringham, 1991). Instead, there appeared to be an overall tendency for participants to overshoot the target for the high compared to low anxiety condition. At first glance, this finding appears to support the riskier *go-for-it strategy* as performers could have tried to cope with the deleterious effect of anxiety in online control by simply eradicating it, and generating a longer displacement in the initial primary movement (Allsop et al., 2016). However, considering the fact that there was no systematic shift in the proportional time to peak velocity, and no alterations in the propensity to undertake two-component submovements, nor commit target errors, suggests such an interpretation may be premature. This argument is corroborated by the fact that the high and low anxiety conditions equally incurred a robust positive skew in the proportion of time to peak velocity (~30% of the total time) and predominantly featured two-component submovements (~80% of trials) meaning visually-regulated online control was most likely undertaken. Instead, it is possible that the tendency to overshoot the primary movements under high state anxiety, while sustaining attempts to process online visual feedback, alludes to a failure in implementing an energy-efficient approach that continues to uphold overall performance. This conjecture clearly corresponds with the central tenets of distraction theories (Eysenck & Calvo, 1992; Eysenck et al., 2007), which state that anxiety has a greater influence on performance efficiency than performance effectiveness.

In reviewing the evidence in online control, there was at least some indication of a deleterious effect of anxiety courtesy of an enhanced endpoint variability and reduced relation between the displacements to and after peak deceleration. Notably, however, the predicted decline in online control in the present study, along with the endpoint variability findings from Allsop et al. (2016), were markedly smaller than that reported by Lawrence et al. (2013). In reconciling these seemingly disparate findings, we may consider the spatial variability exhibited earlier within the movement, as only the present study and Allsop et al. (2016) found a reduction in the early kinematic landmarks for high compared to low anxiety. Thus, it is likely that the between-study differences in the magnitude of effects in online control resulted from the earlier impact on spatial variability that may (e.g., Allsop et al., 2016), or may not (e.g., Lawrence et al., 2013), have manifested following high state anxiety. That is, the fewer measures that are taken in the early portions of the movement, which are designed to nullify the deleterious effects in online control, then the greater the endpoint variability. In this regard, we may alternatively question how it is that anxiety differentially affected the early portions of goal-directed movements across each of the fore mentioned studies. It is possible that these differences can be explained by the variations in the order or scheduling of the high and low anxiety conditions, which may inadvertently affect the organisation of initial primary movements (Elliott et al., 2004) and sensory feedback processing (Khan et a., 1998; Proteau, Martenuik, Girouard, & Dugas, 1987). Although these suggestions are adapted from robust empirical findings, they remain highly speculative and require further investigation.

The general finding of a negative impact of anxiety during online control has been strongly attributed to the disruption of automaticity via explicit monitoring or reinvestment in the conscious control of movement (Lawrence et al., 2013). As a result, previous findings have greatly substantiated the predictions of self-focus theories (Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992). Indeed, this interpretation is based on the assumption that late online control typically recruits implicit processes that operate outside of conscious control. However, it remains elusive whether such slowed control processes comprise unconscious awareness (see Cressman, Franks, Enns, & Chua, 2006; 2007). After all, late online control can be heavily influenced by the pre-planned anticipation of upcoming sensory feedback (Hansen et al., 2006; Khan et al., 2002; Timmis & Pardhan, 2012; Zelaznik, Hawkins, & Kisselburgh, 1983). Thus, it may be possible to explain the previous findings of anxiety-related effects in the context of distraction theories (Calvo & Eysenck, 1992; Eysenck et al., 2007; Eysenck & Wilson, 2016). That is, the deleterious effect of anxiety within online control may manifest from a reallocation of attentional resources to the planning phase of the movement. Indeed, the introduction of a high-pressure or -stress situation may cause worry (e.g., failure to reach performance standards), which in turn leads the performer to allocate their attention to the precise sources of this worry (e.g., motor plan). As a result, there are fewer resources in working memory to deal with the relevant sources of information (e.g., online sensory feedback). Because of this limited resource, the performer may draw upon auxiliary resources (e.g., self-control strength; see Allsop et al., 2016; Englert & Bertram, 2012; Englert & Bertram, 2015) in order to maintain performance standards. Future research may wish to examine these suggestions by incorporating appropriate measures of mental effort (e.g., Rating Scale of Mental Effort (Zijlstra, 1993)) (e.g., Cassell et al., 2017; Lawrence et al., 2013; Wilson et al., 2009), as well as independently manipulating planning (e.g., initial target context) and control (e.g., movement perturbations) to observe how anxiety affects our ability to deal with these types of extreme situations.

In summary, the current findings lend partial support to the framework proposed by Allsop et al. (2016). That is, some accommodation within movement planning coincided with a deleterious effect in online control following high state anxiety. These planning-related modifications were evidenced by a reduced spatial variability and earlier onset deceleration. Despite the failings in online control, the changes witnessed in the planning phase did not extend to a profuse attempt to ‘play-it-safe’ or ‘go-for-it’, where performers would either decrease or increase both the displacement of the primary movement and proportion of time to peak velocity, respectively. Despite the more regular tendency to overshoot the primary movement under high state anxiety, there were no changes in the time dedicated to planning/control, nor the number of trials featuring two-component submovements and endpoint errors. Thus, the deleterious effects in online control may have been solely compensated by drawing a consistent spatial location at peak deceleration while still trying to undertake visually-regulated online control. In the end, overall performance (error, MT) could be successfully upheld, although with limited regard to energy-expenditure (Eysenck et al., 2007). With this in mind, there is a great need to further examine our interpretations, and thus, more closely attribute the impact of anxiety within movement planning to the self-focus or distraction perspectives.

References

Allsop, J. E., Lawrence, G. P., Gray, R., & Khan, M. A. (2016). The interaction between practice and performance pressure on the planning and control of fast target directed movement. *Psychological Research.* doi:10.1007/s00426-016-0791-0.

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), 701-725. doi: 10.1037/0096-3445.130.4.701

Carlton, L. (1981). Processing visual feedback information for movement control. *Journal of Experimental Psychology: Human Perception and Performance, 7*(5), 1019-1030. doi: 10.1037/0096-1523.7.5.1019

Carlton, L. (1992). Visual processing time and the control of movement. In. L. Proteau, & D. Elliott (Eds.), *Vision and motor control* (pp. 3-31). North-Holland, Amsterdam.

Cassell, V. E., Beattie, S. J., & Lawrence, G. P. (2017). Changing performance pressure between training and competition influences action planning because of a reduction in the efficiency of action execution. *Anxiety, Stress, and Coping, 31*(1), 107-120. doi: 10.1080/10615806.2017.1373389

Causer, J., Hayes, S. J., Hooper, J. M., & Bennett, S. J. (2017). Quiet eye facilitates sensorimotor preprogramming and online control of precision aiming in golf-putting. *Cognitive Processing, 18*(1), 47-54. doi: 10.1007/s10339-016-0783-4

Causer, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011). Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion, 11*(3), 595-602. doi: 10.1037/a0023225

Chua, R. & Elliott, D. (1993). Visual regulation of manual aiming. *Human Movement Science, 12*(4), 365-401. doi: 10.1016/0167-9457(93)90026-L

Coombes, S. A., Higgins, T., Gamble, K. M., Cauraugh, J. H., & Janelle, C. M. (2009). Attentional control theory: anxiety, emotion, and motor planning. *Journal of Anxiety Disorders, 23*(8), 1072-1079. doi:10.1016/j.janxdis.2009.07.009

Cressman, E. K., Franks, I. M., Enns, J. T., & Chua, R. (2006). No automatic pilot for visually guided aiming based on colour. *Experimental Brain Research, 171*(2), 174-183. doi:10.1007/s00221-005-0260-2

Cressman, E. K., Franks, I. M., Enns, J. T., & Chua, R. (2007). On-line control of pointing is modified by unseen visual shapes. *Consciousness and Cognition, 16*(2), 265-275. doi:10.1016/j.concog.2006.06.003

Elliott, D., Binsted, G., & Heath, M. (1999). The control of goal-directed limb movements: Correcting error in the trajectory. *Human Movement Science, 18*(2-3), 121-136. doi: 10.1016/S0167-9457(99)00004-4

Elliott, D., Dutoy, C., Andrew, M., Burkitt, J. J., Grierson, L. E. M., Lyons, J. L., Hayes, S. J., & Bennett, S. J. (2014). The influence of visual feedback and prior knowledge about feedback on vertical aiming strategies. Journal of Motor Behavior, 46, 433-443. doi: 10.1080/00222895.2014.933767

Elliott, D., Hansen, S., Grierson, L. E., Lyons, J., Bennett, S. J., & Hayes, S. J. (2010). Goal-directed aiming: two components but multiple processes. *Psychological Bulletin, 136*(6), 1023-1044. doi:10.1037/a0020958

Elliott, D., Hansen, S., Mendoza, J., & Tremblay, L. (2004). Learning to optimize speed, accuracy, and energy expenditure: a framework for understanding speed-accuracy relations in goal-directed aiming. *Journal Motor Behavior, 36*(3), 339-351. doi: 10.3200/JMBR.36.3.339-351

Elliott, D., Helsen, W. F., & Chua, R. (2001). A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychological Bulletin, 127*(3), 342-357. doi: 10.1037//0033-2909.127.3.342

Elliott, D., Lyons, J. L., Hayes, S. J., Burkitt, J. J., Roberts, J. W., Grierson, L. E. M., et al., (2017). The multiple process model of goal-directed reaching revisited. *Neuroscience & Biobehavioral Reviews, 72,* 95-110. doi: 10.1016/j.neubiorev.2016.11.016

Elliott, D. & Madalena, J. (1987). The influence of premovement visual information on manual aiming. *The Quartely Journal of Experimental Psychology: Human Experimental Psychology, 39A,* 541-559. doi: 10.1080/14640748708401802

Elliott, D., Pollock, B. J., Lyons, J. L., & Chua, R. (1995). Intermittent vision and discrete manual aiming. *Perceptual and Motor Skills, 80*(3)*,* 1203-1213.

Engelbrecht, S. E., Berthier, N. E., & O'Sullivan, L. P. (2003). The undershoot bias: learning to act optimally under uncertainty. *Psychological Science, 14*(3), 257-261. doi: 10.1111/1467-9280.03431

Englert, C., & Bertrams, A. (2012). Anxiety, ego depletion, and sports performance. *Journal Sport & Exercise Psychology, 34*(5), 580-599.

Englert, C., & Bertrams, A. (2015). Integrating attentional control theory and the strength model of self-control. *Frontiers in Psychology, 6,* 824. doi:10.3389/fpsyg.2015.00824

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: the processing efficiency theory. *Cognition and Emotion, 6*(6), 409-434. doi: 10.1080/02699939208409696

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion, 7*(2), 336-353. doi:10.1037/1528-3542.7.2.336

Eysenck, M. W. & Wilson, M. R. (2016). Sporting performance, pressure and cognition: Introducing Attentional Control Theory: Sport. In D. Groome & M. Eysenck (Eds.) *An introduction to applied cognitive psychology* (pp. 329-350). London: Routledge.

Gordon, J., Ghilardi, M. F., & Ghez, C. (1994). Accuracy of planar reaching movements. I. Independent of direction and extent variability. *Experimental Brain Research, 99*(1), 97-111. doi: 10.1007/BF00241415

Hansen, S., Glazebrook, C. M., Anson, J. G., Weeks, D. J., & Elliott, D. (2006). The influence of advance information about target location and visual feedback on movement planning and execution. *Canadian Journal of Experimental Psychology, 60*(3), 200-208. doi: 10.1037/cjep2006019

Harris, C. M. & Wolpert, D. M. (1998). Signal-dependent noise determines motor planning. *Nature, 394,* 780-784. doi:10.1038/29528

Jamieson, S. (2004). Likert scales: how to (ab)use them. *Medical Education, 38*(12), 1217-1218. doi: 10.1111/j.1365-2929.2004.02012.x

Khan, M. A. & Binsted, G. (2010). Visual field asymmetries in the control of target-directed movements. In. D. Elliott & M. A. Khan (Eds.), *Vision and goal-directed movement: Neurobehavioral perspectives* (pp. 133-146). Champaign, IL: Human Kinetics.

Khan, M. A., Elliott, D., Coull, J., Chua, R., & Lyons, J. (2002). Optimal control strategies under different feedback schedules: kinematic evidence. *Journal of Motor Behavior, 34*(1), 45-57. doi:10.1080/00222890209601930

Khan, M. A., Franks, I. M., & Goodman, D. (1998). The effect of practice on the control of rapid aiming movement: Evidence for an interdependency between programming and feedback processing. *The Quarterly Journal of Experimental Psychology, 51A*(2)*,* 425-444. doi: 10.1080/713755756

Khan, M. A., Franks, I. M., Elliott, D., Lawrence, G. P., Chua, R., Bernier, P., et al., 2006. Inferring online and offline processing of visual feedback in target-directed movements from kinematic data. *Neuroscience and Behavioral Reviews, 30,* 1106-1121. doi: 10.1016/j.neubiorev.2006.05.002

Khan, M. A., Lawrence, G., Fourkas, A., Franks, I. M., Elliott, D., & Pembroke, S. (2003). Online versus offline processing of visual feedback in the control of movement amplitude. *Acta Psychologica, 113*(1), 83-97. doi: 10.1016/S0001-6918(02)00156-7

Khan, M. A., Lawrence, G. P., Franks, I. M., & Buckolz, E. (2003). The utilization of visual feedback from peripheral and central vision in the control of direction. *Experimental Brain Research, 158*(2), 241-251. doi:10.1007/s00221-004-1897-y

Khan, M. A., Sarteep, S., Mottram, T. M., Lawrence, G. P., & Adam, J. J. (2011). The dual role of vision in sequential aiming movement. *Acta Psychologica, 136*(3), 425-431. doi: 10.1016/j.actpsy.2011.01.010

Krane, V. (1994). The mental readiness form as a measure of competitive state anxiety. *The Sport Psychologist, 8*(2)*,* 189-202. doi: 10.1123/tsp.8.2.189

Lawrence, G. P., Khan, M. A., & Hardy, L. (2013). The effect of state anxiety on the online and offline control of fast target-directed movements. *Psychological Research, 77*(4), 422-433. doi: 10.1007/s00426-012-0440-1

Lawrence, G. P., Khan, M. A., Mottram, T. M., Adam, J. J., & Buckolz, E. (2016). The integration of sequential aiming movements: switching hand and direction at the first target. *Acta Psychologica, 164*, 181-187. doi: 10.1016/j.actpsy.2016.01.005

Lyons, J., Hansen, S., Hurding, S., & Elliott, D. (2006). Optimizing rapid aiming behaviour: Movement kinematics depend on the cost of corrective modifications. *Experimental Brain Research, 174*(1), 95-100. doi:10.1007/s00221-006-0426-6

Masters, R. G. H. (1992). Knowledge, knerves, and know-how: the role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83,* 343-358. 10.1111/j.2044-8295.1992.tb02446.x

Masters, R. & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*(2), 160-183. doi: 10.1080/17509840802287218

Meyer, D. E., Abrams, R. A., Kornblum, S., Wright, C. E., & Smith, J. E. (1988). Optimality in human motor performance: ideal control of rapid aimed movements. *Psychology Reviews, 95*(3), 340-370. doi: 10.1037/0033-295X.95.3.340

Mottet, D., van Dokkum, L. E. H., Froger, J., Gouïach, A., & Laffont, I. (2017). Trajectory formation principles are the same after mild or moderate stroke. *PLoS ONE, 12(3),* e 0173674. Doi: 10.1371/journal.pone.0173674.

Nieuwenhuys, A., & Oudejans, R. R. (2012). Anxiety and perceptual-motor performance: toward an integrated model of concepts, mechanisms, and processes. *Psychological Research, 76*(6), 747-759. doi:10.1007/s00426-011-0384-x

Proteau, L., Martenuik, R. G., Girouard, Y., & Dugas, C. (1987). On the type of information used to control and learn an aiming movement after moderate and extensive training. *Human Movement Science, 6*(*,* 181-199. doi: 10.1016/0167-9457(87)90011-X

Roberts, J. W., Bennett, S. J., Elliott, D., & Hayes, S. J. (2015). Motion trajectory information and agency influence motor learning during observational practice. *Acta Psychologica, 159,* 76-84. doi: 10.1016/j.actpsy.2015.05.011

Roberts, J. W., Blinch, J., Elliott, D., Chua, R., Lyons, J. L., & Welsh, T. N. (2016). The violation of Fitts' Law: an examination of displacement biases and corrective submovements. *Experimental Brain Research, 234*(8), 2151-2163. doi: 10.1007/s00221-016-4618-4

Roberts, J. W., Burkitt, J. J., Elliott, D., & Lyons, J. L. (2016). The impact of strategic trajectory optimization on illusory target biases during goal-directed aiming. *Journal of Motor Behavior, 48*(6), 542-551. doi: 10.1080/00222895.2016.1161588

Roberts, J. W., Elliott, D., Lyons, J. L., Hayes, S. J., & Bennett, S. J. (2016). Common vs. independent limb control in sequential vertical aiming: The cost of potential errors during extension and reversals. *Acta Psychologica, 163,* 27-37. doi: doi.org/10.1016/j.actpsy.2015.10.004

Schmidt, R. & Lee, T. (1999). *Motor control and learning: A behavioural emphasis.* Champaign, IL: Human Kinetics.

Schmidt, R. A., Zelaznik, H. N., Hawkins, B., Frank, J. S., & Quinn, J. T. (1979). Motor output variability: A theory for the accuracy of rapid motor acts. Psychological Review, 86, 415-451. doi: 10.1037/0033-295X.86.5.415

Timmis, M. A. & Pardhan, S. (2012). The effect of central visual impairment on manual prehension when tasked with transporting-to-place an object accurately to a new location. *Investigative Ophthalmology & Visual Science, 53*(6)*,* 2812-2822. doi: 10.1167/iovs.11-8860.

Vine, S. J., Lee, D., Moore, L. J., & Wilson, M. R. (2013). Quiet eye and choking: online control breaks down at the point of performance failure. *Medicine & Science in Sports & Exercise, 45*(10), 1988-1994. doi:10.1249/MSS.0b013e31829406c7

Welsh, T. N., Higgins, L., & Elliott, D. (2007). Are there age-related differences in learning to optimize speed, accuracy, and energy expenditure? *Human Movement Science, 26*(6), 892-912. doi:10.1016/j.humov.2007.04.004

Wilson, M., Chattington, M., Marple-Horvat, D. E., & Smith, N. C. (2007). A comparison of self-focus versus attentional explanations of choking. *Journal of Sport & Exercise Psychology, 29*(4), 439-456. doi: 10.1123/jsep.29.4.439

Wilson, M. R., Vine, S. J., & Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport & Exercise Psychology, 31*(2), 152-168. doi: 10.1123/jsep.31.2.152

Woodworth, R. S. (1899). The accuracy of voluntary movement. *Psychological Review, 3,* (Monograph Suppl.), 1-119.

Worringham, C. J. (1991). Variability effects on the internal structure of rapid aiming movements. *Journal of Motor Behavior, 23*(1), 75-85. doi:10.1080/00222895.1991.9941595

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, 54A*(4), 1143-1154.

Zelaznik, H. Z., Hawkins, B., & Kisselburgh, L. (1983). Rapid visual feedback processing in single-aiming movements. *Journal of Motor Behavior, 15*(3), 217-236. doi: 10.1080/00222895.1983.10735298

Zijlstra, F. R. H. (1993). *Efficiency in work behaviour: A design approach for modern tools.* Delft: Delft University Press (Doctoral Dissertation, Technical University Delft).

Tables

Table 1. Median (IQR) scores from the cognitive sub-scale of the MRF-3, and mean (± SE) of the performance outcome measures as a function of anxiety (units indicated in brackets under dependent measures column; (**) indicates a significant difference (*p* < .05)).

Performance Outcomes	**High**	**Low**
MRF-3 (cognitive) **	3.00 (4.50)	1.50 (2.80)
Error rate (%)	19.22 (1.33)	12.25 (0.63)
Constant error (mm)	.09 (.16)	-0.53 (.06)
Variable error (mm) **	3.33 (.09)	2.90 (.07)
Reaction time (ms)	347.89 (2.74)	363.57 (4.13)
Movement time (ms)	443.82 (4.92)	466.75 (4.76)

Table 2. Mean (± SE) of movement kinematics as a function of anxiety (peak acceleration (PA), peak velocity (PV), peak deceleration (PD), movement end (END)) (units indicated in brackets under dependent measures column; (**) indicates a significant difference (*p* < .05)).

Movement kinematics	**High**	**Low**
Time to PA (ms)	44.62 (.64)	43.98 (.56)
Time to PV (ms)	128.75 (.02)	130.08 (2.32)
Time to PD (ms) **	232.04 (4.69)	245.58 (5.02)
Proportion of time to PV (%)	29.71 (.44)	28.39 (.40)
Displacement at PA (mm)	10.53 (.33)	10.53 (.34)
Displacement at PV (mm) **	103.42 (.87)	98.59 (1.02)
Displacement at PD (mm)	212.75 (1.22)	212.25 (.83)
Displacement at END (mm)	239.69 (.13)	239.18 (.14)
Magnitude of PA (m/s^2)	20.51 (.69)	19.73 (.65)
Magnitude of PV (m/s)	1.43 (.03)	1.34 (.03)
Magnitude of PD (m/s^2)	12.61 (.44)	11.20 (.46)

Table 3. Mean (± SE) of the component submovement measures as a function of anxiety (units indicated in brackets under dependent measures column; (**) indicates a significant difference ($p < .05$)).

Primary movement	**High**	**Low**
Two components (%)	80.86 (1.63)	81.93 (1.59)
Displacement (mm)	240.25 (.21)	239.48 (.23)
Undershoot (%)	14.03 (.70)	18.39 (.84)
On (%)	59.97 (1.38)	63.90 (1.25)
Overshoot (%) **	26.00 (1.53)	17.70 (1.45)

Figure captions

Fig. 1 Representative velocity-acceleration profile of a discrete goal-directed aim. The primary (left) and secondary (right) vertical axes indicate the magnitude of velocity and acceleration, respectively. The *black dotted line* and *grey solid line* indicate the velocity and acceleration respectively across time (horizontal axis). The *solid circles* represent key kinematic landmarks: peak acceleration, peak velocity and peak deceleration in ascending order of time. The *cross-hair* represents the end of a primary submovement and beginning of a secondary submovement (marked by discontinuities in acceleration for this particular example).

Fig. 2 Mean spatial variability (± SE) (mm) as a function of anxiety and kinematic landmark (peak acceleration (PA), peak velocity (PV), peak deceleration (PD), movement end (END)).

Footnotes

1. One participant was removed from the analysis of movement times that were categorized by primary movement outcomes (i.e., undershoot, target hit, overshoot) because they failed to register a single overshoot in at least one of the anxiety conditions.
2. The failure to generate consistent statistical outcomes for VE and spatial variability at the movement endpoint was perhaps due to a number of reasons: both dependent measures were analysed using different statistical models (VE using a standard t-test; spatial variability using Tukey HSD post hoc following an initial omnibus ANOVA), there were subtle variations in the denominator comprising their calculus (VE had no restriction to the degrees of freedom (synonymous with population standard deviation; Schmidt & Lee, 1999); spatial variability was not free to vary (synonymous with sample standard deviation)), and the numerator consisting of the limb's endpoint position was also calculated differently (error scores deriving VE were taken with respect to the absolute end limb position; variability of the movement endpoint was calculated relative to the start of the movement, which may have slightly varied across trials).