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Impact of attentional focus on motor performance within the context of "early" limb regulation and "late" target control

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Abstract

Directing attention to the effect of one's movement (external focus) has been shown to aid performance compared to directing attention to the movement itself (internal focus). This finding has been predominantly explained by an external focus promoting action planning and automatic movement control, ~~and~~while an internal focus act~~sing~~ to constrain movement (constrained action hypothesis [CAH]). In a separate line of research, the multiple control process model states that early movement phases involve anticipated~~, effortful, planning~~ and feedforward ~~mechanisms~~processes, while late movement phases explicitly incorporate ~~automatic processing of online~~external afferent information. We hypothesised that ~~the~~ enhanced planning and automatic movement control would manifest from an external/distal focus compared to internal/proximal focus~~associated with adopting an external focus would result in both greater and more effective planning and enhanced online control in external compared to internal focus of attention conditions~~. The present study had participants execute fast and accurate movements to a single target using a digitizing graphics tablet that translated movements to a screen. Participants were instructed to focus on the end target location (external-distal), movement of the cursor (external-proximal), and the movement of the limb (internal-proximal). It was found that the external-distal focus generated a shorter time to initiate and execute movements (~~representative of~~indicating enhanced movement planning) compared to the external- and internal-proximal conditions. In addition, only the external proximal focus revealed a reduction in spatial variability between peak velocity and movement end (~~representative of greater~~indicating greater online control). These findings indicate that ~~increases~~advances in action planning and online control occur when adopting an external-distal focus~~ of attention~~. However, there were some benefits ~~associated with enhanced~~ to online ~~adjustments~~ control when ~~appear to be specific to~~ adopting an external-proximal focus. ~~Whereas, adopting an external-distal leads to enhanced~~

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action planning. We propose that an external-proximaldistal conditions focus promotes action-effect principles, where there is a greater contribution of anticipatory feedforward processes that limit the need for late online controlthe need for reflexive processes involved in the 'fine-tuning' of movements via the use of afferent information online are reduced due to enhanced feedforward movement planning.

Keywords: attentional focus, constrained-action, early and late control, online, aiming

Introduction

As early as the 19th Century (James, 1890), research has demonstrated that directing attention on the effect of one's movement (external focus) is more efficacious than directing attention to the movement itself (internal focus) (for a review see Wulf 2013). Indeed, the benefit of an external as opposed to internal focus has been reflected in a number domains including sport (golf: Wulf & Su, 2007; pedalo racing: Totsika & Wulf, 2003; soccer: Wulf, McConnell, Gärtner, & Schwarz, 2002; dart-throwing: Marchant, Clough, & Crawshaw, 2007; basketball: Zachry, Wulf, Mercer, & Bezodis, 2005; jumping: Wulf, Zachry, Granados, & Dufek, 2007), muscular control (maximum force production: Marchant, Greig, & Scott, 2009; strength endurance: Marchant, Greig, Bullough, & Hitchen, 2011), and patient populations and rehabilitation (Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002; Johnson, Burridge, Demain, 2013; Landers, Wulf, Wallmann, & Guadagnoli, 2005).

The principle explanation for the benefit of an external focus is adapted from the logic of the *degrees-of-freedom problem.* Here, multiple muscles, limbs and joints may be incomprehensibly utilised to deliver a single or set movement goal (Bernstein, 1967). Indeed, it is suggested that an external focus accommodates automatic control processes – synonymous with self-organization (Kelso, 2012; Wallace, 1996) – whereas, an internal focus causes the performer to "freeze" the degrees-of-freedom. This "freezing" effect results in the decomposing of individual movement elements, which inadvertently attenuates performance (see also, Beilock & Carr, 2001 and Masters, 1992). This notion is referred to as the *constrained-action hypothesis* (CAH) (Wulf, McNevin, & Shea, 2001).

Since its inception, the CAH has been heavily tested for its explanatory power. One of the first studies to do so showed that undertaking an external focus during a balancing task led to shorter amplitude and faster frequency iterative adjustments in movement, as well as shorter probe reaction times in a secondary auditory task compared to an internal focus (Wulf et al., 2001). Indeed, it was theorized that if an external focus of attention accommodates automatic control processes, then there may be more reflex-like adjustments made to the movement in comparison to conditions promoting an internal focus of attention (see also McNevin, Shea, & Wulf, 2003; Wulf, Mercer, McNevin, & Guadagnoli, 2004). This increased automaticity has been shown to result in reduced cognitive demands, and thus leads to a larger pool of attentional resources that are available for a secondary task (*cf.* Poolton, Maxwell, Masters, & van der Kamp, 2007). Recent evidence demonstrates how an external focus may also result in a greater efficiency in the recruitment and activation muscles compared to an internal focus of attention (Marchant, Greigg, Bullough et al., 2011; Marchant, Greig, & Scott, 2009, Vance, Wulf, Töllner, McNevin, & Mercer, 2004). Taken together, these findings present strong support for the CAH.

While the peripheral motor processes underlying the CAH offer a viable explanation for the differences in performance outcomes, it is prudent to consider the neuropsychological processes that underpin such effects. That is, does adopting an external focus more greatly accommodate automatic control via the accumulation of large degrees-of-freedom compared to an internal focus? With this in mind, it may be useful to revisit the ideomotor principle of movement control as movement are a direct consequence of their representation (James, 1890; see also Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997; Wulf & Prinz, 2001). These representations are built-up and contingent upon the movements themselves (e.g., basketball free-throw) and their subsequent consequences to the environment (e.g., ball reaching the basket). Thus, once these links have been established, then they can be innervated in the reverse direction as the presence or attention to relevant stimulus features (e.g., basket) can awaken the action that was once responsible for interacting with these features in the first place (e.g., basketball shot). This perspective is reflected by evidence of an enhanced pre-potent response when in the presence of specialised stimulus features that have been previously correlated with motor-execution (Elsner & Hommel, 2001; see also Heyes, 2001). Although the present study does not depict the coupling between actions and their effects, it is relevant to consider as a framework when trying to explain attentional focus effects. That is, an external focus of attention may cause performers to accrue stimulus features (distal cues) that are more readily correlated to the movements required for skilled execution. Alternatively, an internal focus may cause attention to be distributed to sources of information (e.g., body centred proximal cues) that do not necessarily elicit a skilled response.

With this in mind, it is relevant to consider the role attentional focus in visuomotor control in light of the potential multiple processes at-play (Elliott et al., 2018; Glover & Baran, 2017). That is, the early portion of target-directed movement manifests from pre-response planning, where an internal representation or motor program that models the efferent and reafferent (response-produced) signals is configured (Desmurget & Grafton, 2000; Wolpert & Ghrahmanani, 2000; Wolpert, Miall, & Kawato, 1998). During the movement, and in the event of a discrepancy between the anticipated and actual efferent and reafferent signals, performers can quickly adjust their movement (Grierson & Elliott, 2008; see also, Cluff, Crevecoeur, & Scott, 2015; Smeets, Wijdenes, & Brenner, 2016). These online adjustments unfold very made very early on (<100 ms) and without conscious awareness, which suggests they are automatic in nature (Goodale, Pélisson, & Prablanc, 1986; Proteau, Roujoula, & Messier, 2009; Slachevsky et al., 2001; see also, Cressman, Franks, Enns, & Chua, 2006; Pisella et al., 2000). In this regard, the priming of a sensory-motor representation when adopting an external focus may influence the early phases of movement, which implicates movement planning and automatic rapid adjustments (feedforward-control).

At the same time, it is possible that sensory feedback may be incorporated later on and enable adjustments to be made to the movement with respect to the intended target. This adjustment is substantially different to the form of online control that was previously mentioned as it relies on unanticipated and external sources of afferent information, which is often exploited by early learners (e.g., Elliott, Hansen, Mendoza, & Tremblay, 2004; Proteau, Martenuik, Girouard, & Dugas, 1987). In a similar vein, the limited priming of a sensory-motor representation following an internal focus may restrict the contribution of feedforward processes, and thus require deliberate and inefficient guidance of the movement (feedback-control) (e.g., Hodges et al., 1995; Mottet et al., 2017; Welsh et al., 2007).

To this end, the following study aims to re-examine the influence of attentional focus within the context of the multiple control processes. We consider the notion of multiple control processes to be highly informative for our understanding of attentional focus effects. That is, the action-effect principle may be conceivably enhanced by an external focus, which promotes both enhanced movement planning processes, and the automatic control of movement compared to an internal focus. To investigate, we had participants execute a discrete target-directed movement that was translated to a computer monitor courtesy of a digitizer tablet. At the same time, attention was oriented to the hand (internal-proximal) or target (external-distal), which is synonymous with the standard cues adopted for an internal and external focus, respectively. In addition, focus was directed toward the cursor (responsible for translating the limb movement to the screen) (external-proximal), which de-coupled the proximity to the body and task features. Indeed, if the benefits of an external compared to internal focus are attributed to priming motor codes from task-relevant, distal cues then there should be minimal gains served by an external focus toward other, more proximal, features (e.g., Bell & Hardy, 2009; Castanada & Gray, 2007; McNevin et al., 2003).

Because the influence of an external focus is primarily attributed to the priming of an embedded representation that corresponds with the distal stimulus cues, we predict that the external-distal focus should elicit enhanced feedforward-control that sees a shorter time to initiate and execute the movements. On the other hand, by incorporating an external-proximal condition we are able to mediate the action-effect principle by bringing the external focus away from the intended target. Here, we predict that a more proximal focus should limit feedforward contributions, and enforce feedback-based control that deliberately reduces the discrepancy between the limb and target locations. Additionally, we incorporated a control condition where there was no attentional focus instruction in order to observe whether the potential changes in performance were the result of enhancing or negating said processes.

Method

Participants

Fifteen volunteers agreed to take part in the study (age range = 18-21 years). All were self-declared right-hand dominant, had normal or corrected-to-normal vision and clear of any neurological condition. The study was approved by the University Research Ethics Committee, and designed and conducted in accordance with the Declaration of Helsinki (1964).

Task and Apparatus

Participants were tasked with executing a left-to-right movement toward a digitized target with their right hand as fast and accurately as possible. The movements were detected using a stylus-pen on a digitizing graphics tablet (GTCO Calcomp Drawing Board VI, temporal resolution = 125 Hz, spatial resolution = 1000 lines per inch) and translated for display on a computer screen (temporal resolution = 60 Hz, spatial resolutions = 1024 x 768).

A custom-written computer program was designed to draw stimuli to the screen. A single home (1 cm) and target (1 cm) circle would appear left and right of the participant midline, respectively. The distances between the two circles varied randomly between trials at 16, 20 and 24 cm (centre-to-centre). There was also a cursor circle (0.5 cm), which represented the hand-stylus position. The limb movement coordinates on the graphics tablet directly overlapped with the cursor movement coordinates on the screen (i.e., limb-to-cursor movement ratio = 1:1).

Procedures

Each trial commenced with the presence of a home position (red). Participants positioned the cursor (white) over the home position using the stylus-pen. They would then indicate whether they were ready by depressing the stylus button, which following a variable foreperiod (800-2300 ms; 500 ms steps), caused a target circle (green) to appear. The appearance of the target circle acted as the trials imperative stimulus and informed participants that they should begin the response of aiming for the target as fast and accurately as possible. Upon reaching the end target location participants would again depress the stylus button to progress to the next trial. In the event that participants selected to end the trial without the cursor being inside the target then they were informed of the error and forced to repeat the trial.

There were four different focus conditions contingent upon the instructional set issued by the experimenter: control, internal-proximal, external-proximal, external-distal. In order to avoid biasing participants' automatic or default focus-set, we issued the control condition first where participants had to simply execute fast and accurate movements toward the target. While it is possible that an order effect may manifest from always having the control block first, it is highly unlikely due to the prior number of practice trials (see later for detail) as well as the small number of total trials across the experiment. Indeed, adaptations to similar speed-accuracy trade-off tasks have revealed comparatively scarce effects (Zelaznik, 2018) or require a much larger series of days (Elliott et al., 2004) or trials of practice (Khan, Franks, & Goodman, 1998; Proteau et al., 1987). For the experimental trials, participants were instructed to primarily focus on the moving hand, moving cursor or end target location for each of the internal-proximal, external-proximal and external-distal conditions, respectively (for similar designs, see Lohse et al., 2010; Zachry et al., 2005). In addition, the stimulus screen would display text to remind participants of the designated focus-set ("FOCUS on the HAND/CURSOR/TARGET) both before the first trial, and again at mid-way (i.e., before trial 13) for each block of trials. In order to avoid potentially contrasting sources of visual information that are associated with each of the experimental conditions (Russell, 2007), while remaining consistent with standard oculomotor responses during manual limb movements (Helsen, Elliott, Starkes, & Ricker, 1998; see also, Helsen, Feys, Heremans, & Lavrysen, 2010), we instructed participants to retain their fixation on the target once it appeared. While there are some suggestions that the initial saccade to fixate the target may unfold during the early portions of the movement (before peak acceleration) (see Elliott et al., 2018), it is negligible when considering there is sufficient time to accrue retinal and extra-retinal information from the remaining portions of the limb trajectory.

There was an initial familiarization period were participants would move as fast and accurately as possible to each of the three possible amplitudes (16, 20, 24 cm; 12 trials). The experiment for real showed the different target amplitudes in a fully randomized order. The attentional focus blocks were delivered in a pseudo-random counter-balanced order with the exception of the control block appearing first. There were 24 trials per block, which accumulated to a total of 96 trials (4 blocks). Participants were issued a two-minute break after each block of trials.

Data Processing and Analysis

Movement position data were processed using a second-order, dual-pass Butterworth filter at a low-pass cut-off frequency of 8 Hz. Velocity was obtained by differentiating the resultant position data using a three-point central difference algorithm. Movement onset was defined as the first moment resultant limb velocity reached >20 mm/s, while movement offset was defined as the moment velocity returned to <10 mm/s and >-10 mm/s (for examples of similar procedures, see Khan & Lawrence, 2005; Lawrence, Khan, Buckolz, & Oldham, 2006).

The dependent measures of interest could be categorised into two areas: performance outcomes and movement trajectory. The performance outcome measures that encompassed the temporal domain included reaction time (RT; time difference between stimulus target onset and movement onset) and movement time (MT; time difference between movement onset and movement offset). The endpoint spatial accuracy was quantified courtesy of radial error (RE; distance between movement attempt and target centre) and variable error (VE; population standard deviation of radial error scores). The movement kinematic measures were designed to isolate the planning and control phases of the movement by identifying the moment of peak velocity. Herein, we calculated the time to, time after, magnitude and displacement at peak velocity.

For a more fine-grained assessment of limb trajectory adjustments via feedback-based control, we additionally measured spatial variability of peak velocity and the end of the movement. This measure is adapted from the logic that fast and large-amplitude movements subtend larger amounts of within-participant spatial variability (see Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979) meaning the presence of a delayed intervening control process must assume a decline in variability between the early (peak velocity) and late (endpoint) stages of the movement. More precisely, the spatial variability profiles should differ in form as indicated by a variability ratio between experimental and control conditions (e.g., Khan, Franks et al., 2006; Khan, Lawrence et al., 2003). That is, we separately divided spatial variability for the experimental focus conditions at peak velocity and movement end by the control values at the corresponding kinematic landmarks. To corroborate the spatial variability findings, we calculated Fisher z-transformations of within-participant correlations between the distances travelled to- and after peak velocity. Indeed, strong or robust negative relations would indicate that participants accommodated for the initial limb position by updating the subsequent distance required to accurately hit the target (for similar logic, see Elliott, Binsted, & Health, 1999; Roberts, Elliott, Lyons, Hayes, & Bennett, 2016).

Statistical analysis of select performance outcomes (RT, MT, RE, VE) and movement kinematics (time to, time after, magnitude and displacement at peak velocity), including the within-participant correlations, involved a two-way repeated-measures Analysis of Variance (ANOVA) with 4 levels of focus (control, internal-proximal, external-proximal, external-distal) and 3 levels of amplitude (short, medium, long). Spatial variability ratios were analysed using a three-way repeated measures ANOVA with 2 levels of kinematic landmark (peak velocity, movement end), 3 levels of focus (internal-proximal, external-proximal, external-distal) and 3 levels of amplitude (short, medium, long). Mauchly's test was used to test the assumption of Sphericity, where in the event of a violation ($p > .05$), the Huynh-Feldt correction was adopted when epsilon was >.75, and Greenhouse-Geisser was adopted in the event epsilon was <.75 (original Sphericity-assumed degrees of freedom were reported irrespective of a violation). Significant main and interaction effects featuring more than two means were decomposed using a Tukey HSD post-hoc procedure. Significance was declared at $p < .05$.

Results

Because the multiple target amplitudes were merely designed to force the re-parameterization of movements without anticipation, as well as being independent of our primary research question and hypotheses, only the statistical main and interaction effects featuring the factor of focus are reported.

Performance Outcomes

As shown in Figure 1, there was a significant main effect of focus for RT, $F(3, 42) = 9.23$, $p < .05$, *partial* $\eta^2 = .40$, with control and external-distal conditions generating shorter times to initiate and execute movements compared to the internal-proximal and external-proximal conditions (*ps* < .05). In a similar vein, there was a significant main effect of focus for MT $F(3, 42) = 11.03$, $p < .05$, *partial* $\eta^2 = .44$, with both the control and external-distal conditions being shorter than the external-proximal condition, while the shorter times compared to the internal-proximal condition only reached significance for the comparison with the external-distal condition (*ps* < .05) (see Figure 2). There was also significant main effect for RE, $F(3, 42) = 5.04$, $p < .05$, *partial* $\eta^2 = .27$, with less error generated by the external-proximal condition compared to the control and external-distal conditions (*ps* < .05) (see Table 1). In addition, there was a significant main effect of focus for VE, $F(3, 42) = 2.96$, $p < .05$, *partial* $\eta^2 = .17$, although the post hoc analysis failed to reveal any significant differences (*ps* > .05).

Further to this analysis, we brokered the endpoint variability into the x-axis (primary) and y-axis (secondary) to gauge potential influences on the control of amplitude and direction, respectively (Paillard, 1996; Khan & Lawrence, 2005). Variable error in the x-axis revealed a significant main effect of focus, $F(3, 42) = 4.03$, $p < .05$, *partial* $\eta^2 = .22$, with smaller endpoint dispersion in the external-proximal condition ($M = 4.67$, $SE = .51$)

compared to the control condition (*M* = 6.18, *SE* = .69). In a similar vein, there was a significant main effect of focus for variable error in the y-axis, $F(3, 42) = 5.40$, $p < .05$, *partial* $\eta^2 = .28$, with the external-proximal condition (*M* = 2.08, *SE* = .32) generating smaller dispersion than both the control (*M* = 2.82, *SE* = .31) and external-distal (*M* = 2.60, *SE* = .24) conditions.

[Insert Figure 1 and 2,

and Table 1 about here]

Movement kinematics

There was a significant main effect of focus for the time to peak velocity, $F(3, 42) = 8.43$, $p < .05$, *partial* $\eta^2 = .38$, with the control and external-distal conditions being shorter in time compared to the internal-proximal and external-proximal conditions (see Figure 2). In a similar vein, there was a significant main effect for the time after peak velocity, $F(3, 42) = 8.84$, $p < .05$, *partial* $\eta^2 = .39$, with both the control and external-distal conditions being shorter than the external-proximal condition, while the shorter times compared to the internal-proximal condition only reached significance for the comparison with the external-distal condition (*ps* < .05). There was a significant main effect of focus for the magnitude of peak velocity, $F(3, 42) = 17.01$, $p < .05$, *partial* $\eta^2 = .55$, indicating a large magnitude impulse for the control (*M* = 598.34 mm/s, *SE* = 34.51), and external-distal (*M* = 650.25 mm/s, *SE* = 34.27) conditions compared to the internal-proximal (*M* = 534.73 mm/s, *SE* = 44.49) and external-proximal (*M* = 502.26 mm/s, *SE* = 34.73) conditions (*ps* < .05). In addition, there was a significant Focus × Amplitude interaction, $F(6, 84) = 6.44$, $p < .05$, *partial* $\eta^2 = .32$, indicating differences also between the control and external-distal conditions at medium and short amplitudes, and the internal-proximal and external-proximal conditions at short and medium amplitudes (*ps* < .05). There were no significant main or interaction effects featuring the factor of focus for the mean displacement at peak velocity (*M* = 88.14 mm, *SE* = 1.61), $F(3, 42) = .23$, $p > .05$, *partial* $\eta^2 = .02$, and $F(6, 84) = .77$, $p > .05$, *partial* $\eta^2 = .05$, nor movement end (*M* = 199.96 mm, *SE* = .41), $F(3, 42) = 1.70$, $p > .05$, *partial* $\eta^2 = .11$, and $F(6, 84) = 1.04$, $p > .05$, *partial* $\eta^2 = .07$, respectively.

Online Adjustments

As a principle indicator of adjustments made to the trajectory, the Kinematic landmark × Focus × Amplitude repeated-measures ANOVA on spatial variability ratio revealed a significant main effect of kinematic landmark, $F(1, 14) = 213.59$, $p < .05$, *partial* $\eta^2 = .94$, and no significant main effect of focus, $F(3, 42) = 1.19$, $p > .05$, *partial* $\eta^2 = .08$. Most importantly, there was a significant Kinematic landmark × Focus interaction, $F(3, 42) = 6.91$, $p < .05$, *partial* $\eta^2 = .33$, indicating a significant decline in variability for the external-proximal condition ($p < .05$) (see Figure 3). In order to corroborate these findings, the analysis of within-participant correlations between the distances travelled to and after peak velocity revealed a significant main effect of focus, $F(3, 42) = 10.90$, $p < .05$, *partial* $\eta^2 = .44$, with smaller negative relations for the control (*M* = -1.77 mm, *SE* = .11) and external-distal (*M* = -1.84 mm, *SE* = .09) conditions compared to the external-proximal condition (*M* = -2.29 mm, *SE* = .12) (*ps* < .05), which did not differ from the internal-proximal condition (*M* = -2.03 mm, *SE* = .14) ($p > .05$).

[Insert Figure 3 about here]

Discussion

It has been frequently demonstrated that an external focus of attention elicits greater motor performance than an internal focus; a finding that may be explained by the CAH (Wulf et al., 2001). The CAH suggests that an external focus enables the performer to undertake automatic control of their movement courtesy of the relation between stimulus information and the anticipated response effects (Wulf & Prinz, 2001). The present study reasoned that this internal representation may render a greater influence during the early phases of movement where the performer models the efferent and reafferent signals (Wolpert & Ghrahmanani, 2000; Wolpert et al., 1998). Meanwhile, the latter phases of movement, which incorporates external afferent information, may accommodate limb-target adjustments independent of the fore mentioned representation (Elliott et al., 2018). Thus, it was hypothesized that focus directed toward the target (external-distal) during aiming movements should manifest in a shorter time to initiate and execute responses. However, the advantage served by an external focus may be overturned once external afferent information becomes accessible to deliberate or conscious control (internal-proximal, external-proximal).

Consistent with the vast majority of the attentional focus literature (Wulf, 2013), there was an advantage served by the external-distal focus compared to an internal and/proximal focus. This advantage was highlighted in the shorter time to initiate (RT) and complete (MT) aimed responses, which was distributed in both the time to, and after, peak velocity. Because rapid targeted movements require the succinct handling of efferent and afferent signals (Woodworth, 1899), this may be taken as coarse evidence in favour of the CAH, where performers adopting an external focus are more readily able to control their own movements (Wulf et al., 2001).

Notably, the differences in attentional focus conditions were depicted by the proximity of task features as opposed to the classic differentiation between internal (focus directed to the movement itself) vs. external (focus directed to the movement effect). That is, an external-distal focus (target) additionally rendered superior temporal performance compared to its proximal counterpart (cursor movement). This finding is reflected in previous other studies, which have revealed differences as a function of task features. For example, focus directed to the flight or trajectory of the ball in golf (Bell & Hardy, 2009) and baseball (Casenada & Gray, 2007) have respectively yielded superior spatial and temporal accuracy compared to focus on the motion of the external hitting device. As a result, it is imperative to consider that while an external focus can advance performance relative to an internal focus, it is contingent upon externally focusing on distal features that are somehow related to the task.

Alternatively, nearing the end of the movement, it was found that the advantage served by an external-distal focus was reversed for endpoint accuracy and precision (see Pelleck & Passmore (2017) for similar other findings of the influence of attentional focus on endpoint variability). At first glance, this sudden enhancement in internal- and external-proximal focus may seem to conflict with the frequent message that is to avoid such focus in motor performance and learning. However, the dissociable effects of early temporal (RT, MT) and late spatial variables substantiates our claims of differing contributions of feedforward and feedback processes that underpin attentional focus. That is, the early time to initiate and reach peak velocity, as well as the larger magnitude impulse, generated by the external-distal focus condition may result from the priming of an embedded sensorimotor representation. The innervation of this representation is contingent upon the presence of distal stimulus cues that can be closely matched to movement-execution (Elsner & Hommel, 2001; see Hommel et al., 2001; Prinz, 1997). Herein, the performer may undertake feedforward control, where they can more readily control the early trajectory by comparing the anticipated and actual reafferent signals. Meanwhile, the more refined endpoint response for the proximal focus groups (internal/external) suggests performers were less reliant on priming a sensorimotor representation, and instead, undertook late online adjustments that were related to an explicit comparison between limb and target locations.

With this in mind, it is reasonable to gauge the possibility of dual-task interference, which so often plagues the attentional focus literature (e.g., Poolton et al., 2007). Indeed, providing instructions that cue performers to proximal sources of information could limit the resources that are required to deal with the main distal information. Meanwhile, providing instructions that cue performers to the distal features may allocate resources to something that is already required to be focused on. Nevertheless, the present findings of reduced error and enhanced endpoint control for each of the proximal focus groups would appear to run counter to the potential contaminating influence of a dual-task scenario. Indeed, previous evidence has shown there to be an increase in endpoint error when performers are simultaneously engaged in an independent dual- compared to single-task setting (Khan et al., 2006; Zelaznik et al., 1981). Thus, the present findings could offer a more definitive insight into attentional focus effects by demarcating the movement control processes, and subsequently identifying dissociable influences of attention focus – a distal focus manifests in more automatic feedforward contributions, whilst a proximal focus renders more explicit feedback-based control.

Through further consideration of the spatial endpoint findings, it is relevant perhaps to mention that despite the larger tendency to veer away from target centre, the margin of error generated by the external-distal condition continued to subtend short of the target boundaries (<5 mm) (see Table 1). Hence, it is more likely that the greater accuracy administered by the proximal conditions reflect an unnecessary or overly cautious attempt to avoid an error. This interpretation is supported by the within-participant correlations between the displacements to and after peak velocity, where it was found that the proximal conditions more negatively correlated, and thus, generated more adjustments toward the end of the movement (see Elliott et al., 1999, for similar interpretation). In a similar vein, an internal (proximal) focus directed to the arms during golf-putting has been shown to elicit more overt adjustments to the movement trajectory in an attempt to enhance performance outcomes (Lawrence, Gottwald, Khan, & Kramer, 2012). Indeed, this pattern of motor behaviour is reminiscent of the short-term maladaptive corrections that are evident when performers receive frequent augmented feedback (see Bjork, 1988; Wulf & Shea, 2004). As a result, we may conceive the attempts to correct the limb position following an internal or proximal focus as a negative effect, which in turn, reinforces the constrained-action view that attentional focus negatively influences automatic movement control.

While we have so far focused our discussion on the experimental conditions, it is important to recognise the influence of attentional focus with respect to the control condition (where no focus instructions were issued). Indeed, the provision of a control condition may allude to an advantage or disadvantage of experimental focus conditions. In other words, the typical performance benefit following an external or distal focus compared to control assumes a direct benefit of this particular focus-set. Alternatively, a decline in performance following an internal or proximal focus compared to control assumes an attenuation of this particular focus-set. For the most part, it appeared the external-distal and control conditions were equally advanced in their time to pursue the target and less proficient in endpoint accuracy. These findings would appear to contest any suggestion of an order effect granted the control block was always received first, and thus we may conceive the focus directed at the target as the default focus-set. Meanwhile, the differences in attentional focus throughout the present study allude to alterations that were primarily imposed by the internal and external-proximal focus conditions.

In conclusion, we have extended upon the vast attentional focus literature by further elucidating the sensorimotor processes that underlie attentional focus effects. That is, the focus directed toward the movement or proximal features rendered a less automatic response, which primarily manifested in the early phases of movement. Following the uptake of delayed afferent information, the same focus-set culminated in a more cautious approach to end the movement compared to the control and external-distal focus conditions. In addition to substantiating previous attentional focus effects, and the related CAH (Wulf et al., 2001), we have highlighted influences of attentional focus that may be differentiated as a function of early and late control processes (Elliott et al., 2018). Indeed, the early phases that are attributed to efferent and reafferent processes are contingent upon a primed response evoked by corresponding stimulus information (Prinz, 1997), which we believe is more greatly exposed by an external focus. Alternatively, the latter phases that are attributed to delayed afferent processes are more accessible to conscious intervention, which is synonymous with an internal focus.

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Figure captions

Fig. 1 Mean (±SE) reaction times as a function of attentional focus. (*) indicates a significant difference ($p < .05$).

Fig. 2 Mean (±SE) movement times demarcated into the time to (*grey*) and after (*white*) peak velocity as a function of attentional focus. (*) indicates a significant difference ($p < .05$).

Fig. 3 Mean spatial variability ratio at peak velocity and movement end as a function of attentional focus. Scores <1 indicate less variability than control.

Tables

Table 1. Mean (±SE) scores for radial error (RE) and variable error (VE) as a function of attentional focus. Presented symbols (*,†) indicate specific pairwise comparisons where there was a significant difference (*ps* < .05).

	control	*internal-proximal*	*external-proximal*	*external-distal*
RE	4.61* (.64)	4.35 (.70)	3.56*† (.52)	4.49† (.61)
VE	3.51 (.44)	3.14 (.48)	2.86 (.43)	3.46 (.37)