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An internal focus of attention is optimal when congruent with afferent proprioceptive task information

Gottwald, Vicky; Owen, Robin; Lawrence, Gavin; McNevin, Nancy

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Abstract

Whilst benefits of an external focus are shown to govern several characteristics of skill execution, specificity theory indicates that sources of afferent information most useful to performance execution are typically prioritised during processing.

Objectives: We investigated whether an internal focus facilitates performance when pertinent afferent information is proprioceptive in nature and congruent with attentional focus. We also considered whether the mechanisms behind attentional focus differences are attributable to planning processes or online motor control.

Design: Experiments 1 and 2 adopted a randomised design, whilst experiment 3 used a repeated measures approach.

Method: In Experiment 1 we investigated movement variability as a measure of planning and error correction under external and internal focus conditions in an aiming task. Experiment 2 removed visual information to increase pertinence of proprioceptive feedback for movement execution and Experiment 3 adopted a leg-extension task, where proprioceptive salience was enhanced using an ankle weight. We hypothesized that this would increase congruency between internal focus instructions and movement production.

Results: Experiments 1 and 2 revealed reduced amplitude errors under an internal focus whilst Experiment 3 showed similar findings with the addition of lower EMG activity when adopting an internal focus. Movement variability findings were indicative of enhanced planning.

Conclusions: When pertinence of proprioceptive information was amplified, benefits of an internal focus were more pronounced and performance was higher. Participants were better able to focus on movement characteristics to process proprioceptive feedback: something not afforded under an external focus. This raises doubts regarding the rigidity of the constrained action hypothesis.

1 Provision of effective instructions can play a significant role in shaping the quality of
2 deliberate practice and subsequently help maximise skill acquisition (Ericsson, Krampe & Tesche-
3 Römer, 1993). Equally, recent literature has begun to identify contexts where certain instructions
4 can impede performance. There is now a compelling body of evidence that demonstrates the
5 advantages of adopting an external (i.e., centered toward movement effects) over internal (i.e.,
6 centred toward body movements) focus of attention, in governing several characteristics of skill
7 execution such as accuracy, consistency, and economy (for a review see Wulf, 2013). One
8 mechanism thought critical in accounting for these advantages is movement planning (e.g. Prinz,
9 1997; Lohse, Sherwood & Healy, 2010). Whilst we are typically aware of the intended goal of
10 particular movements, it is the responsibility of the executive motor system for the selection,
11 programming, and initiation of the action: often a complex pattern of specific muscle activities. In
12 sporting actions, we will plan where a particular limb will finish up at the end of a movement
13 (Woodworth, 1899; Schmidt, Zelaznik, Hawkins, Frank, & Quinn Jr, 1979). It is this planning
14 process specifically, that is often suggested to account for attentional focus differences.

15 Focus differences were first recognised during early experimental research requiring
16 participants to focus on movement effects as opposed to body movements themselves (Wulf, Höb,
17 & Prinz, 1998). When this happened, performance was superior. As well as performance accuracy,
18 advantages in attentional capacity have contributed to the development of the constrained action
19 hypothesis (Wulf, McNevin & Shea, 2001). This suggests that focusing on the effects of one's
20 movements promotes automaticity in movement execution and prevents any undesirable
21 interference in response programming and control (likely to occur as a result of focusing internally).
22 Findings have also been accounted for with Prinz's (1997) action effect principle, which
23 emphasizes a compatible relationship between movement planning and outcome. Thus, if actions
24 are planned and controlled in relation to their effects, then focusing externally should facilitate
25 performance by enhancing congruence between movement planning and the desired response.

1 Similarly, Wulf and Lewthwaite's (2016) OPTIMAL (optimising performance through intrinsic
2 motivation and attention for learning) theory of motor learning proposes enhanced goal-action
3 coupling when using an external focus of attention. Offering further support for this notion, Wulf
4 (2015) states that "adopting an external focus is related to the *planning* of movement, but has
5 nothing to do with the processing of intrinsic feedback or bodily awareness, or lack thereof"
6 (p.337). However, regardless of theoretical hypotheses, pertinent variables are yet to be rigorously
7 tested, including the effect of focus of attention on movement planning and control mechanisms,
8 especially in non-continuous tasks. A minority of researchers have begun to explore planning
9 processes as a function of focus of attention, but as a secondary aim and often with methodological
10 limitations in the approach adopted (e.g. Lohse et al., 2010; Lohse, 2012).

11 Work by Lohse et al. (2010) hypothesised higher levels of explicit processing when
12 employing an internal focus of attention in a dart-throwing task. Dependent variables included a
13 proxy measure of planning (preparation time between throws) with explicit processing expected to
14 be reflected via increases in inter-trial intervals when adopting an internal focus. Findings were
15 consistent with this notion and viewed as a manifestation of enhanced planning when using an
16 external focus of attention. However, Lohse (2012) concedes the rudimentary nature of this
17 approach to investigate planning. This measure was refined accordingly to calculate pre-movement
18 times, this time in an isometric force production task. Pre-movement times were measured as the
19 time from the 'go' signal to a change in recorded force of +/-1 lb. Findings revealed lower pre-
20 movement times for those adopting an external focus of attention early on in the learning process.

21 However, attentional focus researchers have negated to consider important modifications
22 that may be made *during* an action to achieve an intended goal i.e., motor control. Seminal
23 attentional focus studies investigating balance board performance (e.g. Wulf et al., 1998; Wulf et
24 al., 2001) imply that benefits of an external focus of attention may be due to corrections made
25 during the movement. One could consider this to be online control and therefore less related to

1 planning. In an aiming movement, these control mechanisms involve any movement adjustments
2 necessary to correct discrepancies between the end of a limb's initial impulse and its target
3 (Woodworth, 1899; Elliott, Helsen & Chua, 2001). With both planning and control mechanisms
4 heavily integrated, it would be remiss not to consider them in the context of one another, especially
5 being that aiming movements incorporate both pre-planned offline (feedforward) and online
6 (somatosensory) adjustments (Elliott, Chua, Pollock, & Lyons, 1995; 20 & Kawato, 1998; Khan,
7 Elliott, Coull, Chua, & Lyons, 2002; Elliott et al., 2014).

8 Whilst the aforementioned findings (Lohse et al., 2010; Lohse, 2012) are in line with
9 attentional focus hypotheses surrounding movement planning, we would argue that in the absence
10 of motor control measures, it is difficult to fully understand information processing or 'trade-offs'
11 between planning and control in the context of focus of attention. Ironically, findings are accounted
12 for using Willingham's (1998) control-based learning theory (COBALT), which only reinforces the
13 importance of investigating differences in output control as well as planning. COBALT is a
14 neuropsychological theory of skill learning. Its framework provides support for a series of
15 perceptual-motor processes, which occur largely outside of conscious control (i.e., goal selection),
16 motor sequencing (i.e., planning), and muscle activation. However, target selection and planning
17 processes can also occur as a more conscious process whereby they are coded in egocentric as
18 opposed to allocentric space. Lohse (2012) suggests that adopting an internal focus of attention is
19 more likely to induce this egocentric coding and thus, conscious control over actions. This is
20 arguably more attention demanding and accounts for increased planning demands, which then
21 manifest through longer inter-trial intervals and pre-movement times. However, Willingham (1998)
22 proposes that both conscious and unconscious modes of skill execution can be helpful to
23 performance.

24 In the absence of any investigations into movement 'control' in conjunction with planning
25 processes, the current set of studies are the first to include rigorous measures of these mechanisms.

1 In turn, this also provides a novel application of Khan et al.'s (2006) variability methodology,
2 which has been shown to provide a robust measure of both planning (i.e., *offline* cognitive
3 processing of feedback between trials for movement planning) and control (i.e., *online* adjustments
4 made during a movement) processes. This approach has been most often adopted in rapid aiming
5 tasks, which afford a rigorous analysis of kinematic profiles of movements. The methodological
6 technique initially stems from Woodworth's (1899) aforementioned two-component model of goal-
7 directed aiming (for a more recent review see Elliott et al., 2001). This provides a detailed analysis
8 of two proposed phases of target-aiming movements: an initial impulse phase, which consists of
9 central planning to move the limb into the vicinity of the target followed by an adjustment phase,
10 which controls the movement using sensory feedback in order to reach the target. Measures of
11 variability provide useful indications of these components' relative contributions to movement
12 execution. Whilst errors early on in an action tend to be indicative of poor motor planning, control
13 processes typically occur online and can be reflected in error corrections made later in a movement
14 trajectory (see Khan et al., 2006 for a review).

15 Furthermore, literature has also observed instances where attentional shifts *towards* and not
16 away from movements have been advocated, such as process goals (Zimmerman & Kitsantas, 1997)
17 or external/kinaesthetic motor imagery (Hardy & Callow, 1999). Similarly, the philosophical
18 concept of a functional 'somaesthetic awareness' (Shusterman, 2011) has been proposed by Toner
19 and Moran (2015) for use in making movement adjustments for error correction or when re-learning
20 movements. This is in line with arguments made by Collins, Carson and Toner (2015) highlighting
21 reported benefits from athletes sometimes adopting a focus towards particular aspects of a
22 movement. They suggest that optimal focus is dependent on factors such as familiarisation with
23 instructions, focus relevance and availability of physical implements during execution (see also
24 Lawrence, Gottwald, Hardy, & Khan, 2011). These movement related techniques are clearly
25 contradictory to Wulf's persuasive recommendations cautioning against a 'movement centred'

1 focus (see Wulf, 2013 for a review). We hypothesize that these discrepancies are likely a result of
2 task nuances and that adopting a movement centred focus may actually add value in particular
3 contexts yet to be explored. When performing an aiming movement, available sensory information
4 in the form of either visual or proprioceptive and kinaesthetic information is utilised in guiding the
5 limb to the target via offline and online motor control (Crossman & Goodeve, 1983). According to
6 specificity of practice hypothesis (Proteau, 1992; Coull, Tremblay, & Elliott, 2001), the source of
7 afferent information most useful to performance execution is typically prioritised for processing. In
8 an aiming task where proprioception is an arguably important source of information, we might
9 expect this to manifest via enhanced processing (e.g. planning or control) when using an internal
10 and not external focus of attention. This is in line with the aforementioned phenomenon of a
11 facilitative somaesthetic awareness (Shusterman, 2011). Interestingly, Porter, Wu, and Partridge
12 (2010) reveal that 84.6% of athletes surveyed report that instructions provided in their training still
13 induce an internal focus of attention, regardless of Wulf and colleagues' recommendations. Whilst
14 this may be a function of undesirable coaching methods, it may also be an indication of potential
15 benefits of an internal focus in some contexts e.g. when importance of proprioceptive information is
16 high for task success. The current series of experiments are aimed at better understanding this
17 research lacuna in the context of offline motor planning and online motor control mechanisms. We
18 conducted three experiments that differed systematically in the need for proprioceptive processes to
19 meet task goals, whilst incorporating rigorous measures of planning and control.

20 **Experiment 1**

21 In Experiment 1 we compared the utilisation of afferent information for offline planning and
22 online motor control processes under different attentional focus conditions. Participants completed a
23 computer-based rapid-aiming task, under either internal or external attentional foci. We
24 hypothesized benefits in offline planning when adopting an internal focus of attention, in line with

1 specificity theory. In a task of this nature, we expected greater congruence between internal
2 compared with external focus instructions and the required movement production.

3 **Method**

4 **Participants.**

5 Forty participants, who reported right-hand-dominance and normal / corrected-to-normal
6 vision, were randomised into two groups: internal focus of attention ($n = 20$) and external focus of
7 attention ($n = 20$). G*Power (G*Power 3; Faul, Erdfelder, Lang, & Buchner, 2007) sample size
8 estimation deemed 14 participants per group necessary to provide power = .8 for the interaction
9 between focus of attention and within movement trajectory variability when $\alpha = .05$ and $\eta_p^2 =$
10 .05. Thus, final sample size exceeded minimum power requirements. The experiment was
11 conducted in accordance with institutional ethical guidelines.

12 **Apparatus and task.**

13 The experimental task comprised a target-directed computer-based aiming movement,
14 performed using a handheld stylus on a Calcomp III digitising tablet (122cm x 91.5cm & sample
15 rate 200Hz) placed horizontally in front of participants (see figure 1). An opaque shield obscured
16 participants' vision of their hand/stylus. Stylus position was denoted via a white circular cursor
17 (1cm diameter) on a black background using a 37" Mitsubishi Diamond Pro monitor (refresh rate =
18 85hz) located 33cm in front of the participant and 20cm above the digitizing tablet. The X/Y
19 movement of the stylus on the tablet plane corresponded 1-to-1 to the X/Y movement of the cursor
20 on the monitor plane. A green circular 'start' marker (1cm diameter) was located at the bottom of
21 the monitor. Three circular 'target' markers (red, 1cm diameter) were each displayed 20cm centre-
22 to-centre from the start position marker; one target was directly above the start marker and the other
23 two targets were at 10° to either side (angle subtended from the home position). The rationale for
24 including multiple targets was purely to increase task complexity and thus for analysis purposes,
25 data was later collapsed across targets. To begin each trial, participants steadied their cursor over

1 the start marker, after which one of the targets turned green. Following a random 500-1500ms
2 delay, a GO-tone signalled participants to initiate movement towards the target. Participants were
3 instructed to: (1) make their movements as smoothly as possible; (2) stay within a criterion
4 movement time (MT) of 400-500ms to allow sufficient time for processing of visual information
5 (Carlton, 1992; Khan et al., 2003)¹; and (3) be as accurate as possible in stopping their cursor over
6 the target - therefore giving the task a directional and amplitude component. Once participants had
7 come to a complete stop, the target became red again and participants had to return to the start
8 position, ready for the next trial; concurrently, knowledge of results in the form of MT and a point
9 score (see Allsop, Lawrence, Gray & Khan, 2017) was presented on the monitor². It was explained
10 to participants at the beginning of testing that they were not required to make movements as fast as
11 possible and that as long as they moved within 400-500ms, their performance would be determined
12 by aiming accuracy and not reaction time nor MT. If trials had a MT <400ms or >500ms, they were
13 repeated until correct.

14 -----
15 Insert Figure 1 here
16 -----

17 **Procedure.**

18 The experimenter demonstrated the task up to five times to participants. Before starting their
19 first trial, participants in the internal group were instructed to focus on the fluid motion of their
20 hand, and participants in the external group were instructed to focus on the fluid motion of the pen.
21 Participants were given attentional focus reminders every 10 trials. Participants completed three

¹ Based on the rationale for including a MT criterion, we have not included any MT analysis within dependent measures and results sections.

² The point score was a direct measure of performance and calculated using a combination of how close the participant was to meeting the criterion MT (in terms of absolute error) and how close their movement finished in relation to the target (end-point error). A maximum of five points were possible for each of the two components, meaning a maximum of 10 points were possible on any one trial. The maximum score of 10 was achieved if MT fell within ± 10 ms of the criterion MT and cursor error fell within ± 5 mm of the criterion target distance. These points reduced by one whole integer for every additional ± 10 ms and every additional ± 5 mm that the cursor fell outside of the criterion MT and the criterion target distance, respectively.

1 experimental phases: acquisition (90 trials), retention (30 trials), and transfer (30 trials). Retention
2 trials required participants to perform the same task with no focus reminders. The transfer task was
3 the same as retention, but targets were located 25cm as opposed to 20cm from the start position.
4 Target order was randomised within each block of trials, under the condition that the same target
5 could not appear twice in a row.

6 **Data reduction and dependent measures.**

7 Displacement data was filtered using a second-order dual-pass Butterworth filter with a
8 10Hz low-pass cut-off frequency. A two-point central finite difference algorithm was used to
9 calculate instantaneous velocity data from displacement data. This process was repeated to calculate
10 acceleration data from velocity data. Movement initiation was defined as the point at which the
11 cursor moved 2mm from the start position. Movement end was defined as the point where absolute
12 velocity of the stylus fell below 1mm/s: thus prohibiting reversal movements. The 100% start-to-
13 target distance was defined as the point at which the cursor crossed the invisible arc subtended by
14 the three targets. Amplitude error comprised the stylus' orthogonal deviation (mm) from the same
15 invisible arc. Overshoots were numerically positive whilst undershoots were numerically negative.
16 Directional error comprised the stylus' orthogonal deviation (mm) from the longitudinal axis
17 connecting the home and target marker. Deviation to the left of this axis was numerically negative
18 whilst deviation to the right of this axis was numerically positive. Trials whose amplitude or
19 directional error deviated by $>2SD$ from the given participant's trial block mean for $>25\%$ of the
20 movement distance were removed prior to analysis (4.40% of all trials were removed).

21 Outcome performance was inferred from constant error (CE), absolute error (AE), and
22 variable error (VE): each calculated once from amplitude error (at movement end) and once from
23 directional error (at 100% start-to-target distance). CE and VE respectively comprised the within-
24 participant mean and standard deviation of error. AE comprised the within-participant mean of
25 absolute error. Planning and online motor control's role in the production of outcome performance

1 was inferred from variability (i.e., within-participant standard deviation) throughout amplitude and
2 directional components of movement. Amplitude variability was calculated at peak acceleration
3 (pka), peak velocity (pkv), peak negative acceleration (pkna), and movement end (end) from the
4 cursor's numerical orthogonal deviation in amplitude (mm) from the start position. Directional
5 variability was calculated from directional error, at 25, 50, 75, and 100% of the start-to-target
6 distance. Offline planning efficacy was inferred from variability at pka to pkv in the amplitude
7 component, and from variability at 25% of the start-to-target distance in the directional component.
8 Corrective feedback loops should have had insufficient time to initiate before these points and
9 therefore improved planning efficacy can be inferred from reduced variability (Khan et al., 2006).
10 Online motor control efficacy was inferred from changes in variability between pkv, pkna, and end
11 for the amplitude component and changes in variability between 75% and 100% of movement
12 distance for the directional component. In line with variability methodology, this 'deceleration'
13 typically reflects corrective processes via the 'braking of the limb in order to accurately home in on
14 the target'. Improved online motor control efficacy can be inferred from reductions in variability
15 between these points (Khan et al., 2006). Finally, to rule out speed-accuracy trade-offs, MT (ms)
16 (time interval between movement start and movement end) was calculated and compared between
17 focus conditions.

18 **Analysis.**

19 Since the rationale for including multiple targets within the task was for task complexity
20 purposes only (as opposed to any theoretical hypotheses), data were collapsed across targets.
21 Outcome performance was inferred from separate 2 Focus of Attention (external and internal) x 3
22 Trial Block (acquisition, retention, and transfer) ANOVAs on endpoint amplitude and directional
23 CE, AE, and VE (i.e., 6 omnibus ANOVAs). Offline planning's contribution to outcome
24 performance in the amplitude component of movement was inferred from a 2 Focus of Attention
25 (external and internal) x 3 Trial Block (acquisition, retention, and transfer) x 2 Marker (pka and

1 pkv) ANOVA on amplitude component VE. Offline planning's contribution to outcome
2 performance in the directional component of movement was inferred from a 2 Focus of Attention
3 (external and internal) x 3 Trial Block (acquisition, retention, and transfer) ANOVA on directional
4 component VE at 25% movement distance. Online control's contribution to outcome performance
5 in the amplitude component of movement was inferred from a 2 Focus of Attention (external and
6 internal) x 3 Trial Block (acquisition, retention, and transfer) x 3 Marker (pkv, pkna, and end)
7 ANOVA on amplitude component VE. Online control's contribution to outcome performance in the
8 directional component of movement was inferred from a 2 Focus of Attention (external and
9 internal) x 3 Trial Block (acquisition, retention, and transfer) x 2 Distance (75 and 100%) ANOVA
10 on directional component VE. Greenhouse-Geisser corrected tests are reported when the sphericity
11 assumption was violated in omnibus analyses. Significant omnibus interactions were broken down
12 using planned repeated contrasts.

13 **Results**

14 **Outcome performance**

15 *Amplitude component.* The results of the 3 Trial Block x 2 Focus of Attention ANOVAs on
16 endpoint amplitude CE, AE, and VE are shown in Table 1B. Analysis of CE revealed a significant
17 main effect for focus of attention and a significant Trial Block x Focus of Attention interaction. The
18 significant focus of attention main effect revealed that the internal group generally had less endpoint
19 amplitude CE than the external group. Breakdown of the Trial Block x Focus of Attention
20 interaction revealed the internal group significantly decreased whilst the external group
21 significantly increased their CE from acquisition to immediate retention ($F_{1, 38} = 4.34, p = .044, \eta_p^2$
22 $= .10$) but not significantly from immediate retention to transfer ($F_{1, 38} = 2.20, p = .146, \eta_p^2 = .06$)
23 (see Figure 2). Analysis of AE revealed a significant main effect for focus of attention and a
24 significant Trial Block x Focus of Attention interaction. The focus of attention main effect revealed
25 that the internal group generally had less endpoint amplitude AE than the external group.

1 Breakdown of the Trial Block x Focus of Attention interaction revealed a significant interaction
2 from acquisition to immediate retention and a non-significant interaction from immediate retention
3 to transfer ($F_{1, 38} = 4.10, p = .050, \eta_p^2 = .10$; $F_{1, 38} = 2.05, p = .161, \eta_p^2 = .05$, respectively). Analysis
4 of VE revealed only the main effect for group as significant: wherein the internal group generally
5 had less endpoint amplitude VE than the external group.

6 **Directional component.** The results of the 3 Trial Block x 2 Focus of Attention ANOVAs
7 on 100% start-to-target distance CE, AE, and VE are shown in Table 1B. Analysis of CE revealed
8 no significant main effects nor interaction. Analysis of AE revealed only the main effect for trial
9 block as significant. Breakdown of this main effect revealed no significant change from acquisition
10 to immediate retention but a significant increase from immediate retention to transfer ($F_{1, 38} = .15, p$
11 $= .699, \eta_p^2 < .01$; $F_{1, 38} = 18.46, p < .001, \eta_p^2 = .33$, respectively). Analysis of VE also revealed only
12 the main effect for trial block as significant. Breakdown of this main effect revealed no significant
13 change from acquisition to immediate retention but a significant increase from immediate retention
14 to transfer ($F_{1, 38} = .79, p = .379, \eta_p^2 = .02$; $F_{1, 38} = 13.85, p = .001, \eta_p^2 = .27$, respectively).

15 -----
16 Insert Figure 2 here
17 -----

18 **Offline planning / online control contributions to outcome performance.**

19 **Amplitude component.** The results of the 2 Focus of Attention x 3 Trial Block x 2 Marker
20 ANOVA on amplitude variability to infer offline planning efficacy are shown in Table 1d. This
21 analysis revealed a significant main effect for focus of attention and no significant interaction
22 involving focus of attention. The results of the 2 Focus of Attention x 3 Trial Block x 3 Marker
23 ANOVA on amplitude variability to infer online motor control efficacy are also shown in Table 1D.
24 This analysis revealed a significant main effect for focus of attention and no significant interaction
25 involving focus of attention. Overall, the presence of a significant main effect for focus of attention
26 in both analyses (wherein an internal focus produced less variability than an external focus) and

1 absence of significant interactions involving focus of attention, suggest that changes in offline
2 planning and not online control were the primary contributor to the internal focus group’s superior
3 endpoint amplitude performance.

4 ***Directional component.*** The results of the 2 Focus of Attention x 3 Trial Block ANOVA on
5 directional variability to infer offline planning efficacy are shown in Table 1d. This analysis
6 revealed no significant focus of attention main effect and no significant interaction involving focus
7 of attention. The results of the 2 Focus of Attention x 3 Trial Block x 2 Distance ANOVA on
8 directional variability to infer online control efficacy are shown in Table 1D. This analysis also
9 revealed no significant focus of attention main effect and no significant interaction involving focus
10 of attention. In sum, no significant offline planning and online control differences emerged between
11 focus of attention groups in the directional component of movement.

12 -----
13 Insert Table 1 here
14 -----

15 **Discussion**

16 Experiment 1 employed a novel use of variability methodology to investigate planning and
17 control mechanisms under an internal and external focus of attention. This was carried out in a task
18 where proprioceptive salience was hypothesized to be high. Participants performed a target-aiming
19 task, during which key kinematic variables indicative of motor planning and control processes could
20 be measured (see Khan et al., 2006). We hypothesized that the proprioceptive nature of the task
21 may contribute to atypical findings based on the philosophical concept of a functional ‘somaesthetic
22 awareness’ (Shusterman, 2011): wherein the increased congruence between task-relevant
23 information and an internal focus of attention would yield performance and processing benefits
24 compared to an external focus.

25 Findings confirmed that participants adopting an internal focus were more accurate in their
26 movements comparative to those adopting an external focus. This was manifested via reduced

1 errors throughout all experimental phases as well as decreasing levels of error between acquisition
2 and retention. Participants adopting an external focus displayed the opposite pattern of results.
3 Furthermore, variability findings were reflective of more consistent (i.e., less variable) movements
4 under an internal focus of attention. It is likely that in a rapid-aiming target-directed movement,
5 higher levels of variability may be detrimental to movement accuracy. This is inconsistent with
6 Lohse et al. (2010) where enhanced performance was manifested by increased variability. However,
7 Bernstein (1967) suggests that movements are constrained to the point that they are most functional.
8 The presence of a focus of attention main effect for amplitude variability, but absence of significant
9 interactions involving focus of attention (which would be indicative of movement adjustments made
10 during the movement), suggests that the primary contributor to improved endpoint amplitude
11 performance of the internal group was offline planning.

12 Thus, an internal focus of attention may possess some facilitative attributes when
13 performing a task of this nature, where fine motor adjustments are required (whether made during a
14 movement or prior to). The results of Experiment 1 are likely a reflection of unequal levels of
15 proprioceptive information available under different focus conditions in a task of this manner.
16 Participants adopting an internal focus of attention may have been better afforded proprioceptive
17 information (i.e., somaesthetic awareness) due to the nature of their instructions. This important role
18 of attentional focus in skill refinement has been deliberated previously in a series of commentaries
19 (see Toner & Moran, 2015, Wulf, 2015; Toner & Moran, 2016), which propose that focusing on the
20 body can be of benefit for refining skills and making movement adjustments. It is therefore
21 plausible that an internal focus may possess the required characteristics for these error-correction
22 mechanisms to occur most effectively. This benefit may be further enhanced within tasks that are
23 more ‘proprioceptive’ in nature.

24 However, it might be argued that a rapid aiming task with both visual and proprioceptive
25 information available was not truly proprioceptive in nature and makes it difficult to determine the

1 extent to which discrete modes of information (i.e., visual versus proprioceptive awareness), were
2 most useful to participants' motor execution when adopting different attentional foci. Thus, the
3 rationale behind Experiment 2 was to remove this confound by applying task constraints which
4 accentuated the significance of proprioceptive information for successful performance. This was to
5 confirm whether tasks where proprioception is integral to performance, benefit from adopting an
6 internal compared to external focus of attention.

7 **Experiment 2**

8 In aiming tasks, available sensory information through vision or proprioception is
9 fundamental for successful movement execution (Crossman & Goodeve, 1983). As previously
10 mentioned, specificity of practice hypothesis (Proteau, 1992; Coull et al., 2001) proposes that the
11 source of afferent information deemed most useful to successful performance is usually prioritised
12 for processing. Identifying the source of this information is helpful in informing both theoretical
13 advancement as well as the development of practical performance and learning interventions
14 (Toussaint, Meugnot, Badets, Chesnet, & Proteau, 2016). Experiment 2 aimed to remove the
15 confound of visual information from Experiment 1 and provide robust evidence for the benefits of
16 an internal focus when congruent with sources of task relevant afferent information available.
17 Otherwise, the task remained unchanged.

18 We hypothesised that if those adopting an internal focus are indeed able to process
19 proprioceptive information more readily and in line with specificity theory (Proteau, 1992), then we
20 would expect to see a further benefit of an internal focus under no vision conditions. Khan et al.
21 (2006) suggest that variability profiles differ depending on afferent information available. It is thus
22 plausible that the availability of visual feedback will modulate focus of attention effects on
23 movement variability.

24 **Methods**

1 The only difference between Experiment 2 and Experiment 1's methodological approach
2 was that vision of the cursor on the screen was removed at the beginning of each trial until
3 movement end (e.g. consistent with Chua & Elliott, 1993; Khan et al., 2003). Targets remained
4 visible throughout. Participants were again randomised into two groups; internal (n=20) and
5 external (n=20) and provided with the same instructions as per Experiment 1. Sample size was
6 based on the estimation detailed in Experiment 1. Of all trials, 3.03% were identified as outliers and
7 removed prior to analysis. Again, target data was collapsed based on experimental hypotheses.

8 **Results**

9 **Outcome performance.**

10 *Amplitude component.* The results of the 3 Trial Block x 2 Focus of Attention ANOVAs on
11 endpoint amplitude CE, AE, and VE are shown in Table 2B. Analysis of CE revealed a significant
12 main effect for trial block and focus of attention. Breakdown of the main effect for trial block
13 revealed CE generally increased (i.e., greater overshoot) from acquisition to immediate retention
14 ($F_{1,38} = 4.94, p = .032, \eta_p^2 = .12$) and decreased from immediate retention to transfer ($F_{1,38} = 42.54,$
15 $p < .001, \eta_p^2 = .53$). To break down the main effect for focus of attention, one sample t-tests
16 comparing each group's mean CE across trial blocks to 0 were performed. This analysis revealed
17 the external group generally undershot the target ($t(19) = -1.87, p = .078, 95\% \text{ CI } [-32.20, 1.85]$)
18 and the internal group generally overshot the target ($t(19) = 4.11, p = .001, 95\% \text{ CI } [10.44, 32.13]$).
19 Analysis of AE revealed only the Trial Block x Focus of Attention interaction as significant.
20 Breakdown of this interaction revealed that there was no interaction between acquisition and
21 immediate retention ($F_{1,38} = 2.08, p = .157, \eta_p^2 = .05$), but between immediate retention and
22 transfer, the external group significantly increased whilst the internal group decreased their AE ($F_{1,$
23 $38 = 11.61, p = .002, \eta_p^2 = .23$). Analysis of VE revealed only the main effect for trial block as
24 significant. Breakdown of this trial block revealed that generally VE increased significantly from

1 acquisition to immediate retention ($F_{1,38} = 17.64, p < .001, \eta_p^2 = .32$) and from immediate retention
2 to transfer ($F_{1,38} = 9.38, p = .004, \eta_p^2 = .20$).

3 **Directional component.** The results of the 3 Trial Block x 2 Focus of Attention ANOVAs
4 on 100% start-to-target distance CE, AE, and VE are shown in Table 2B. Analysis of CE revealed
5 no significant main effects nor interaction. Analysis of AE revealed a significant main effect for
6 trial block and focus of attention. The focus of attention main effect revealed that generally, the
7 internal group had less AE than the external group (see Figure 3). Breakdown of the main effect for
8 trial block revealed that generally AE significantly increased from acquisition to immediate
9 retention ($F_{1,38} = 8.32, p = .006, \eta_p^2 = .18$) and from immediate retention to transfer ($F_{1,38} = 7.54, p$
10 $= .009, \eta_p^2 = .17$). Analysis of VE revealed a significant main effect for trial block and a near-
11 significant main effect for focus of attention. The main effect for focus of attention trended towards
12 the internal group exhibiting less VE than the external group. Breakdown of the main effect for trial
13 block revealed that generally AE significantly increased from acquisition to immediate retention
14 ($F_{1,38} = 17.64, p < .001, \eta_p^2 = .32$) and from immediate retention to transfer ($F_{1,38} = 9.38, p = .004,$
15 $\eta_p^2 = .20$).

16 -----
17 Insert Figure 3 here
18 -----

19 **Offline planning / online control contributions to outcome performance.**

20 **Amplitude component.** The results of the 2 Focus of Attention x 3 Trial Block x 2 Marker
21 ANOVA on amplitude variability to infer offline planning efficacy are shown in Table 2D. This
22 analysis revealed no significant main effects nor interactions involving focus of attention. The
23 results of the 2 Focus of Attention x 3 Trial Block x 3 Marker ANOVA on amplitude variability to
24 infer online motor control efficacy are also shown in Table 2. This analysis also revealed no
25 significant main effects nor interactions involving focus of attention. In sum, within the amplitude

1 component we observed no differences in offline planning / online control based on focus of
2 attention.

3 ***Directional component.*** The results of the 2 Focus of Attention x 3 Trial Block ANOVA on
4 directional variability to infer offline planning efficacy are shown in Table 2D. This analysis
5 revealed a significant focus of attention main effect and no significant interaction involving focus of
6 attention. The results of the 2 Focus of Attention x 3 Trial Block x 2 Distance ANOVA on
7 directional variability to infer online control efficacy are shown in Table 2. This analysis revealed a
8 significant focus of attention main effect and a significant Focus of Attention x Trial Block x
9 Distance interaction. The focus of attention main effect revealed that the internal focus group
10 generally had less VE than the external focus group. Breakdown of the Focus of Attention x Trial
11 Block x Distance interaction revealed that from immediate retention to transfer only, the external
12 group increased their VE less between 75 and 100% movement distance than the internal group ($F_{1,38} = 4.69, p = .037, \eta_p^2 = .11$): at first glance suggesting increased online correction in the external
13 group at transfer. However, given (1) this effect being exclusive to transfer, (2) transfer likely
14 increasing task difficulty compared to immediate retention, and (3) the internal group exhibiting
15 superior planning and outcome performance compared to the external group, the external focus
16 group likely exhibits increased online control at transfer because worse planning provides greater
17 scope for correction: rather than greater corrections being a specific benefit of an external focus of
18 attention. In sum, the consistent focus of attention main effects and absence of Focus of attention x
19 Distance interaction across trial blocks, suggest that offline planning likely accounts for focus of
20 attention differences in outcome performance.
21

22 -----
23 Insert Table 2 here
24 -----

25 **Discussion**

1 The rationale behind Experiment 2 was to investigate motor programming strategies under
2 conditions of enhanced afferent information in the mode of proprioception. This was the first
3 experiment to consider both planning and control mechanisms as a function of focus of attention in
4 a truly proprioceptive task. In line with Experiment 1 findings, we hypothesised enhanced accuracy
5 for those adopting an internal as opposed to external focus. This was as a consequence of enhanced
6 congruence between an internal focus of attention and afferent information available in the form of
7 proprioception. Additionally, it was expected that increased movement accuracy would be coupled
8 with evidence of enhanced planning strategies under an internal focus. To test this, Experiment 2
9 applied task constraints through the removal of visual information to accentuate the significance of
10 proprioceptive information for successful performance.

11 Error data provided further support for Experiment 1 findings, with some nuances.
12 Amplitude CE data suggests that participants tended to make greater errors and overshoot the target
13 when using an internal focus, whilst those adopting an external focus tended to undershoot with
14 smaller errors. However, amplitude AE data provides a clearer picture during later experimental
15 phases, with the external group increasing error between retention and transfer and the internal
16 group showing the converse pattern of results. Amplitude VE findings reinforce this pattern of
17 results, showing a marginally significant main effect ($p = .05$) for focus of attention, with those
18 adopting an internal focus displaying more consistent movements. Furthermore, directional
19 variability findings suggest that the primary contributor to the improved directional outcome
20 performance of the internal group was increased efficacy of offline planning. This was reflected in
21 decreased directional variability early on in movement trajectories and supports the notion of a
22 facilitative somaesthetic awareness. It should however be noted that benefits of end-point amplitude
23 accuracy were accounted for only in directional and not amplitude variability findings. It might be
24 that an absence of amplitude variability findings were a consequence of differences in the
25 ‘functionality’ of variability between an internal and external focus. This may account for no

1 differences here in line with Bernstein (1967) and Lohse et al. (2010) degrees of freedom.
2 Experiments 1 and 2 differed in the extent to which the task emphasised the importance of
3 proprioceptive information for performance success. This was achieved through the availability of
4 vision. However, experiment 3 allowed us to manipulate the strength or ‘potency’ of proprioceptive
5 feedback. We felt that this would provide more robust evidence for an argument recommending that
6 focus of attention should be congruent with afferent information pertinent for task success.

7 **Experiment 3**

8 Experiment 2 lends support to the notion that an internal attentional focus may be effective
9 for both movement planning and accuracy when performance-relevant afferent information
10 primarily stems from proprioception. Experiment 3 sought to provide further evidence for this by
11 manipulating proprioceptive salience. Participants had to encode body (i.e., leg) positions and
12 reproduce them as accurately as possible.

13 This task was adopted from Toussaint et al.’s (2016) methodology, which investigated leg-
14 positioning recall, where the availability of proprioceptive information was modified in an effort to
15 prevent neglect of proprioceptive feedback. In this case, proprioceptive information was
16 manipulated by attaching small weights to the ankle of participants. Findings revealed that when
17 both vision and proprioception were available, proprioceptive information was neglected and vision
18 was the dominant force in producing accurate movements. However, the addition of ankle weight
19 increased ‘proprioceptive strength’ during the task, thus reducing proprioceptive neglect. The
20 current experiment aimed to investigate whether different attentional foci facilitate the utilisation of
21 proprioceptive information to reproduce accurate movements and whether modifying the strength of
22 proprioceptive information would encourage greater congruence between participants’ internal
23 focus of attention and the goal of the task.

24 Electromyography (EMG) of the quadriceps was also measured to provide a rigorous
25 measure of movement efficiency. Afferent information was manipulated in different ways. Firstly

1 vision was removed. Toussaint et al.'s (2016) work emphasizes the dominant role of visual
2 feedback in goal directed movements when available and thus, removal of this allowed researchers
3 to isolate proprioceptive information. Secondly, it was felt that the nature of this task better allowed
4 for participants to code the target location proprioceptively compared to Experiments 1 and 2:
5 further increasing proprioception's relevance to movement accuracy. Thirdly, based on the findings
6 of Toussaint and colleagues, weight was added to the ankle of one group in an effort to increase the
7 strength of proprioceptive information available during the task.

8 Thus, the rationale for the final experiment was to investigate whether manipulating the
9 congruence between an internal focus of attention and the afferent information available, enhances
10 the extent to which movements are executed successfully. It was hypothesised that, in line with
11 Experiments 1 and 2, an internal focus would facilitate performance by directing participants'
12 attention to task-relevant proprioceptive information. Furthermore, it was expected that attentional
13 focus differences would be more pronounced in the group performing with an ankle weight due to
14 increased potency of proprioceptive information.

15 **Methods**

16 **Participants.**

17 The makeup of participants in Experiment 3 (n=40) replicated that of Experiments 1 and 2,
18 other than an additional participation criterion being no history of nervous or muscular disorders.
19 Participants were randomised into weight (n=20) and no-weight groups (n=20). Sample size was
20 again based on the estimation detailed in Experiment 1.

21 **Apparatus.**

22 Participants were seated in the middle of a 12-camera volume (Vicon Nexus, sampling at
23 240hz) on a chair modified to minimise camera obstruction and allow participants' non-dominant
24 leg to move freely and comfortably around the knee joint. As in Toussaint et al. (2016) and
25 Toussaint and Blandin (2010), participants' non-dominant leg was used to perform the task: to

1 reduce the chance of a ceiling effect and increase task novelty (Beilock, Carr, MacMahon, &
2 Stalkes, 2002). The weight group had a 0.5kg sand-bag wrapped tightly around the base of their
3 non-dominant leg's ankle, whilst the no-weight group did not. Leg movement in 3D space was
4 captured via the coordinates of four reflective markers: one placed on the lateral condyle, medial
5 condyle, lateral malleolus, and medial malleolus. A custom Microsoft Visual Basic script computed
6 a live mid-point between the condyle markers, and between the malleolus markers, respectively.
7 From these midpoints, a digital plane was computed to represent the lower leg position. At the
8 beginning of testing, participants were asked to let their leg hang freely and relaxed. This position
9 denoted their start position in every trial and a wooden box was placed so their heel gently touched
10 the front face of the box when in this position (to aid start-position consistency). Before every trial,
11 the experimenter ensured participants' leg was within ± 1 degree of the starting position. Leg angle
12 was calculated live (at 240hz) as the difference in position between the start position and the plain
13 representing their lower leg. Single-differential electromyography (EMG) surface electrodes (DE
14 2.1, Delsys, Boston, MA) were placed on the vastus medialis and vastus lateralis of participants'
15 non-dominant leg to provide an electromyographical measure of leg extension efficiency (Alkner,
16 Tesch, & Berg, 2000). Electrode placement and site preparation was in line with SENIAM
17 recommendations (Hermens et al., 1999). Each EMG electrode's signal was 10k amplified
18 (Bagnoli-2, Delsys) and digitized at 2500Hz using a computer running Spike2 software (Cambridge
19 Electronic Design).

20 **Experimental procedure and design.**

21 Every trial comprised an encoding and recall phase respectively. For the encoding phase,
22 participants were instructed to slowly extend their leg from the start position until a tone sounded –
23 indicating participants were within $\pm 1^\circ$ of the target position. Participants then had to hold and
24 mentally encode this angle for 2 seconds. Once the tone had sounded for 2 seconds: the precise leg
25 position was recorded as the 'encoded position'; the tone changed to a higher pitch; and participants

1 had to return to the start position. Upon participants' return to the start position, following a random
2 foreperiod between 1.5 and 2.5 seconds, the recall phase was initiated via a GO-tone for movement
3 initiation. For the recall phase, participants were instructed to: reproduce the target angle as
4 accurately as possible (basing task exclusively on the amplitude); produce one smooth and straight
5 movement within a MT between 500 and 1000ms; not concern themselves with their reaction time;
6 and hold their recalled position for 1 second at the end, before returning to the start position (ready
7 for the next trial) (see figure 4). Following each trial, participants were provided with knowledge of
8 results on a monitor in front of them; this consisted of recall phase error (i.e., by how many degrees
9 they had undershot or overshot the target position) and MT (i.e. the ms time interval between
10 movement initiation and end). If trials had a MT <500ms or >1000ms, they were repeated until
11 correct. As in Toussaint et al. (2016), participants were not permitted to open their eyes from the
12 beginning of the encoding phase, to the end of the recall phase: thus creating a proprioception-only
13 task.

14 -----
15 Insert Figure 4 here
16 -----

17 Experimental trial blocks constituted familiarisation (15 trials), acquisition 1 (30 trials),
18 transfer 1 (30 trials), acquisition 2 (30 trials) and transfer 2 (30 trials). Familiarisation and
19 acquisition targets were 122, 132 and 142°. In transfer, participants were given new targets, which
20 were 117, 127 and 147°. Participants were informed of this. Target order was randomised between
21 participants and trial blocks: with the stipulation that targets were never repeated immediately. At
22 familiarisation, participants were given no focus of attention instructions. At acquisition 1, half of
23 participants were given external focus of attention instructions (“focus on the markers, and how you
24 move them to their correct position”) and the other half internal focus of attention instructions
25 (“focus on your leg, and move it to its correct position”). At acquisition 2, participants were given
26 the focus of attention instructions they did not receive in acquisition 1. It was highlighted to

1 participants that it was very important for them to stick to their prescribed focus of attention. At
2 acquisition, focus reminders were provided at every trial for the first five trials, after which they
3 were given every 10 trials. At transfer, participants were given no reminders. As a manipulation
4 check, after every block of trials, participants were given a piece of paper to write down what they
5 focused on in their block of trials; participants were asked to provide sufficient detail for someone
6 else to replicate their focus. In summary the present study design entailed a within-group trial block
7 factor and counterbalanced within-group focus of attention factor for weight and no-weight groups.

8 **Data reduction and dependent measures.**

9 During testing, a custom Microsoft Visual Basic two-point central finite difference
10 algorithm was used to calculate instantaneous velocity data from displacement data. This process
11 was repeated to calculate acceleration data from velocity data. Movement initiation was defined as
12 the data point where velocity dropped to <1 degree per second. Movement end was defined as one
13 data point before leg velocity reached ≤ 0 : meaning movements could not have a reversal in
14 movement direction. MT for participants' post-trial feedback was defined as the time (ms) between
15 movement initiation and movement end. Recall phase error for participants' feedback was defined
16 as the angular deviation between leg angle at movement end and the target position; overshoots
17 were labelled numerically positive and undershoots numerically negative. For post-testing analysis,
18 using a custom LabView script, leg displacement data was filtered using a second-order dual-pass
19 Butterworth filter with a 10Hz low-pass cut-off frequency. Movement start, end and time were re-
20 calculated using this filtered data. Additionally, four kinematic markers were calculated using
21 custom LabView scripts. Namely, peak acceleration (pka), peak velocity (pkv), peak negative
22 acceleration (pkna) and movement end (end). Encoding error for analysis was calculated as the
23 angular deviation between movement end and the encoded position. Overshoots were labelled
24 numerically positive and undershoots numerically negative.

1 Trials whose angular movement distance deviated by $>2SD$ from the given participant's trial
2 block mean for $>25\%$ of the movement distance were removed prior to analysis (2.07% of all
3 trials). Data of participants who did not change their focus ($n=5$) between acquisition 1 and 2, based
4 on two researchers' impression of the manipulation check responses, were also removed from
5 analysis (see below examples and resulting group sizes³). Dependent measures were based on
6 LabView-filtered data and included: MT; encoding CE (mean within-participant encoding error);
7 and encoding VE (standard deviation of within-participant encoding error). Spatial variability
8 throughout the amplitude of movement was assessed via variability in movement degrees at each
9 kinematic marker (i.e., pka, pkv, pkna, and end). There was no directional component to the task.

10 Vastus medialis and vastus lateralis EMG activity (in V) for each trial was analysed offline
11 from 20ms before movement start until movement end: using custom MATLAB scripts
12 (MathWorks Inc., Natick, MA). EMG activity was filtered using a bidirectional fourth order
13 bandpass (20-450hz) Butterworth filter, rectified, and integrated to attain a measure of muscular
14 activation within the context of time (i.e., iEMG).

15 **Analysis.**

16 For brevity and clarity, the analysis on endpoint CE, endpoint AE, endpoint VE, and VE at
17 each kinematic marker, used data collapsed across targets; separate 3 Target (low, medium, and
18 high) x 2 Trial Block (acquisition and transfer) x 2 Focus of Attention (internal and external)
19 ANOVAs for each weight group were performed on endpoint CE, AE, and VE to ensure collapsing
20 targets was appropriate and revealed no significant interactions involving targets. To ensure the
21 counterbalanced subsets of participants did not differ at the beginning of testing, familiarisation
22 iEMG and familiarisation endpoint MT, CE, AE, and VE were submitted to independent samples t-

³ Examples statements that suggested participants did not adhere to the appropriate focus: an external focus that was reported as focusing on "using muscle memory based on how tense the leg muscle is", "leg speed and trying to keep my leg still" or comments which suggested the participant was using neither an internal nor external focus e.g. "my mind was more neutral", "I wasn't really focused on a specific thing". Post data-reduction $n=35$ (No-weight external 1st then internal = 10; No-weight internal 1st then external = 8; Weight external 1st then internal = 7; Weight internal 1st then external = 10).

1 tests which compared external-to-internal and internal-to-external focus of attention subgroups,
2 within each weight condition (i.e. two comparisons per-dependent variable). To investigate focus of
3 attention's effect on muscular efficiency and outcome performance, iEMG of the vastus lateralis
4 and iEMG of the vastus medialis were then analysed using separate 2 Weight (weighted and no-
5 weight) x 2 Trial Block (acquisition and transfer) x 2 Order (external-to-internal and internal-to-
6 external) x 2 Focus of Attention (internal & external) ANOVAs. The effect of focus of attention on
7 offline planning was investigated via separate 2 Trial Block (acquisition and transfer) x 2 Focus of
8 Attention (internal and external) 2 Order (external-to-internal and internal-to-external) x 2 Marker
9 (pka and pkv) ANOVAs for each weight group (weighted and no-weight). The effect of focus of
10 attention on online control was investigated via separate 2 Trial Block (acquisition and transfer) x 2
11 Focus of Attention (internal and external) x 2 Order (external-to-internal and internal-to-external) x
12 3 Marker (pkv, pkna, and end) ANOVA for each weight group (weighted and no-weight). The
13 purpose of the order factor was to determine whether switching from an internal to an external focus
14 of attention, or vice versa, impacted performance. The assumption for sphericity held in all analyses
15 since no more than two levels of within-subject factors were compared.

16 **Results**

17 **Test of equivalence for counterbalanced subsets**

18 T-tests comparing familiarisation CE of external-to-internal and internal-to-external focus of
19 attention subgroups within weight and no-weight groups revealed no significant difference in the
20 no-weight group ($t(16) = -.45, p = .659, 95\% \text{ CI } [-4.83, 3.14]$) nor the weight group ($t(15) = 1.06, p$
21 $= .306, 95\% \text{ CE } [-1.52, 4.52]$). T-tests comparing familiarisation AE of external-to-internal and
22 internal-to-external subgroups within weight and no-weight groups revealed no significant
23 difference in the no-weight group ($t(16) = -.79, p = .444, 95\% \text{ CI } [-4.37, 2.01]$) nor the weight group
24 ($t(15) = 1.07, p = .302, 95\% \text{ CE } [-1.12, 3.38]$). T-tests comparing familiarisation VE of external-to-
25 internal and internal-to-external focus of attention subgroups within weight and no-weight groups

1 revealed no significant difference in the no-weight group ($t(16) = -1.53, p = .144, 95\% \text{ CI} [-1.39,$
2 $.22]$) nor the weight group ($t(15) = 1.29, p = .216, 95\% \text{ CE} [-.31, 1.25]$). The T-tests comparing
3 familiarisation iEMG of external-to-internal and internal-to-external focus of attention subgroups
4 within weight ($t(16) = -.17, p = .869, 95\% \text{ CE} [-.04, .03]$; $t(16) = .64, p = .533, 95\% \text{ CE} [-.01, .03]$,
5 respectively for vastus medialis and vastus lateralis) and no-weight ($t(15) = 1.41, p = .178, 95\% \text{ CE}$
6 $[-.01, .06]$; $t(16) = -.10, p = .924, 95\% \text{ CE} [-.03, .03]$, respectively for vastus medialis and vastus
7 lateralis) groups revealed no significant difference and therefore subgroups should be comparable.

8 **Outcome performance.**

9 Results of the 2 Focus of Attention x 2 Trial Block x 2 Order ANOVAs on weight and no-
10 weight groups' CE, AE, and VE are shown in table 3B. Analysis of the no-weight group CE
11 revealed a near-significant Trial Block x Focus of Attention x Order interaction (see figure 5, panels
12 A, C, and E) and a significant main effect for trial block: with no other significant main effects nor
13 interactions. The main effect for trial block revealed acquisition generally featured significantly less
14 CE than transfer. Analysis of the weighted group CE revealed a near-significant focus of attention
15 main effect and significant Focus of Attention x Order interaction (see figure 5, panels B, D and F):
16 with no other significant main effects nor interactions. Specifically, when weighted participants
17 adopted an internal focus towards the end of testing, their CE was significantly reduced. Analysis of
18 the no-weight group AE revealed only a significant main effect for trial block: wherein acquisition
19 generally featured significantly less AE than transfer. Analysis of the weighted group AE revealed
20 no significant main effects nor interactions. Analysis of the no-weight group VE revealed only a
21 significant trial block main effect: wherein acquisition generally featured significantly less VE than
22 transfer. Analysis of the weighted group VE revealed no significant main effects nor interactions.

23 **Offline planning / online control contributions to outcome performance.**

24 Results of the 2 Trial Block x 2 Focus of Attention x 2 Marker ANOVAs performed on the
25 weight and no-weight groups to infer offline planning efficacy are shown in Table 3D. Analysis of

1 the no-weight group revealed only significant main effects for trial block and marker and a
2 significant Focus of Attention x Trial Block interaction. Breakdown of the Focus of Attention x
3 Trial Block x Order interaction revealed that when an internal focus of attention came second,
4 variability was reduced. Analysis of the weighted group revealed significant main effects for trial
5 block and marker and a significant Focus of Attention x Trial Block x Marker x Order interaction.
6 Breakdown of this interaction also revealed that when an internal focus of attention came second,
7 variability was reduced but only in acquisition and at peak velocity (by which point differences in
8 planning should be at their most prominent). Results of the 2 Trial Block x 2 Focus of Attention x 2
9 Marker ANOVAs performed on the weight and no-weight groups to infer online control efficacy
10 are shown in Table 3D. Analysis of neither the no-weight group nor the weighted group revealed
11 any significant interactions involving markers. In sum, these results suggest that differences in
12 outcome performance based on focus of attention are primarily facilitated via changes in planning.

13 -----
14 Insert Table 3 here
15 -----

16 **Muscle activity.**

17 The 2 Focus of Attention x 2 Trial Block x 2 Weight x Order ANOVA on the vastus
18 lateralis iEMG revealed a significant main effect for focus of attention ($F_{1,31} = 4.86, p = .035, \eta_p^2 =$
19 $.14$) and Focus of Attention x Weight x Order interaction ($F_{1,31} = 8.06, p = .008, \eta_p^2 = .21$).
20 Specifically, an internal ($M = .058, SD = .029$) generally yielded lower iEMG compared to an
21 external focus ($M = .060, SD = .024$) and the Focus of Attention x Weight x Order interaction
22 followed the same pattern of results as CE. The 2 Focus of Attention x 2 Trial Block x 2 Weight x
23 Order ANOVA on the vastus medialis iEMG revealed a main effect for focus of attention and Focus
24 of Attention x Weight x Order interaction which trended in the same direction (as the vastus
25 lateralis data) but were not significant ($F_{1,31} = 2.92, p = .097, \eta_p^2 = .09; F_{1,31} = 3.35, p = .077, \eta_p^2 =$
26 $.10$, respectively).

1 -----
2 Insert Figure 5 here
3 -----

4 **Discussion**

5 Experiment 3 utilised an amplitude-only leg extension task based on that of Toussaint et al.
6 (2016). Participants were tasked with encoding target leg positions and accurately reproducing them
7 in one fast target-directed movement, under counterbalanced external and internal focus of attention
8 instructions. We aimed to ascertain whether, contrary to the assertions of the constrained action
9 hypothesis (Wulf et al., 2001), an internal focus of attention can facilitate superior performance:
10 specifically, when proprioceptive feedback strength was increased via an ankle weight. It was
11 hypothesised that, compared to an external focus of attention, an internal focus would facilitate
12 superior performance, because it guides participants' attention to task-relevant proprioceptive
13 information. These external / internal focus of attention differences were hypothesised to be stronger
14 in the group performing with an ankle weight.

15 Outcome performance was inferred from overall endpoint CE, AE, and VE. Results revealed
16 that for the weighted group, participants who adopted an internal focus later in testing, reduced their
17 CE during acquisition trials. Furthermore, the weighted group's CE exhibited a near-significant focus
18 of attention main effect ($p = .052$) and a significant focus of attention by marker interaction: wherein
19 adopting an internal focus reduced CE compared to an external focus. Specifically, an internal focus
20 significantly reduced CE when it was the second focus participants were given (i.e., later in testing,
21 after an external focus). These effects were not significant for the weighted group's AE, but followed
22 the same trends as per their CE. Concerning the weighted group's endpoint VE, there was no
23 difference between external and internal groups. Past studies may help us understand the mechanisms
24 behind our observed focus of attention order effects (McNevin, Shea, & Wulf, 2003; Wulf et al.,
25 1998). Focus of attention effects in novices seemingly manifest during later testing phases. Therefore,
26 in Experiment 3, an internal focus may have been more beneficial when provided following an

1 external focus because by that point, it could be argued that participants were more accustomed to
2 utilising the proprioceptive feedback of the task. There is a body of literature suggesting enhanced
3 proprioceptive neural mechanisms over time through neuroplasticity as a function of practice /
4 dependency (Schwenkreis, Pleger, Höffken, Malin & Tegenthoff. 2001; Goble, 2010; Xerri, 2012).

5 In sum, the endpoint results of Experiment 3 demonstrate that an external focus does not
6 always facilitate ‘best’ performance. Instead the improved CE and (although non-significantly)
7 improved AE, combined with decreases in VE at pkv, suggest that an internal focus overall facilitated
8 superior outcome performance over an external focus when the task was reliant on proprioception
9 and proprioceptive strength was high (i.e. within the weight group). The internal focus’ performance
10 superiority seemingly originated within offline movement planning based on decreased variability at
11 key kinematic markers attributable to planning mechanisms (i.e., pkv) for those adopting an internal
12 focus. Concurrently, an internal focus yielded less EMG compared to an external focus, suggesting
13 that adopting an internal focus facilitates more efficient / appropriate planning of muscle activation
14 when tasks are proprioception-based. Overall, Experiment 3 lends further credence to the notion that,
15 contrary to the constrained action hypothesis of Wulf et al. (2001), an internal focus can be superior
16 to an external focus: provided proprioceptive strength and pertinence is high.

17 Analyses were conducted to ensure the aforementioned performance differences were due to
18 focus of attention instructions and not confounds. Focus of attention effects were investigated using
19 a repeated measures design and data analysis considered whether focus of attention order (i.e.,
20 external focus 1st and internal focus 2nd, or vice versa) influenced findings. To ensure the external-
21 to-internal and internal-to-external subsets of participants within each weight group were comparable,
22 independent samples t-tests compared these subsets’ endpoint MT, CE, AE, and VE at familiarisation
23 (i.e., the beginning of testing where participants were not yet prescribed a focus of attention). This
24 analysis revealed no significant differences.

25 **General Discussion**

1 The last decade has seen considerable advances in our understanding of the more pertinent
2 characteristics in formulating effective instruction. Endorsement of externally focused and implicit
3 information in promoting automaticity of movements seems well grounded in the literature, with
4 mechanisms such as Prinz's (1997) 'action-effect principle' and Wulf et al.'s (2001) 'constrained action
5 hypothesis' conveying similar messages. Nevertheless, this theoretical understanding has failed to
6 align with mechanisms accounting for the benefits of process goals and external/kinaesthetic motor
7 imagery, both of which encourage attentional shifts towards and not away from movements. The
8 current investigation has attempted to begin to address this research lacuna, over three experiments
9 designed to identify nuances where an internal focus may be useful. This is in line with a proposed
10 facilitative 'somaesthetic awareness' (Shusterman, 2011; Toner & Moran, 2015) when making error
11 corrections or re-learning movements.

12 In essence, it has not yet been specifically tested whether it is changes in offline planning,
13 online movement adjustments, or both forms of motor control that facilitate improved outcome
14 performance with an external focus of attention, nor whether an internal focus of attention also has
15 the capability to enhance components of motor control / outcome performance when pertinent task
16 information is of proprioceptive (i.e. internal) nature. A noteworthy effort to partially address the
17 former research lacuna was by Lohse and colleagues (2010; 2012). Two studies respectively utilised
18 time between trials and pre-movement time to infer offline movement planning efficiency. In line
19 with the conjecturing of the constrained action hypothesis (Wulf et al., 2001), both studies
20 demonstrated that an external focus of attention facilitated improved force-production accuracy,
21 whilst concurrently reducing the time used for offline planning: indicating reduced conscious
22 processing and increased automaticity compared to an internal focus of attention. However, two
23 limitations of these studies are that, firstly, time used for offline planning was a measure of efficiency
24 (i.e., how many cognitive resources were utilised) rather than efficacy (i.e., how good the movement
25 plan was) and secondly, online motor control's role within performance was not explicitly measured.

1 Therefore, offline planning and/or online motor control's precise contribution to the creation of
2 outcome performance under different foci of attention is unknown. Our first experiment aimed to
3 address this question via a fast target-directed visual aiming task, wherein the variability methodology
4 of Khan et al. (2006) was used to simultaneously infer offline planning and online motor control's
5 contribution to outcome performance.

6 The results of Experiment 1 revealed no differences between foci in the directional component
7 of movement, but within the amplitude component, the internal group displayed reduced (i.e.
8 superior) movement endpoint CE, AE, and VE compared to the external group. In sum, participants
9 exhibited superior outcome performance when an internal focus was adopted. Variability findings
10 confirmed that focus of attention-based differences manifest within offline movement planning. The
11 internal group demonstrated overall reduced variability throughout movement compared to the
12 external group, but the shape of these variability profiles did not differ. The underlying processes
13 yielding Experiment 1's results are likely several fold. Firstly, the fine motor skill nature of our visual-
14 aiming task likely raised the pertinence of proprioceptive information. The internal group may have
15 been able to exploit the congruent (i.e., internal in nature) feedback of the task and achieve better
16 performance than the external group via improved movement planning. Secondly, differences may
17 have manifested within the amplitude component of movement because the impulse and resultant
18 proprioceptive feedback generated to move the hand an amplitude of 20cm, to the target, should be
19 exponentially greater than any impulse / feedback generated within the directional component.

20 Experiment 2 and 3 aimed to further Experiment 1 by increasing the congruence between
21 pertinent task characteristics and participants' internal focus of attention. Experiment 2 removed
22 vision during the aiming task to increase proprioceptive task demands (i.e., participants had to identify
23 target locations through proprioception only). In line with our hypotheses, results revealed that an
24 internal focus overall yielded superior outcome performance within the amplitude and direction
25 components of movement. Analysis of variability throughout movement lent further credence to the

1 notion that focus of attention effects originate within offline movement planning for non-continuous
2 tasks. As in Experiment 1, movement variability was reduced with an internal compared to an external
3 focus, but the shape of variability profiles did not differ. Finally, Experiment 3 aimed to build on
4 Experiment 2 via the utilisation of a leg-extension task and the modulation of proprioceptive feedback
5 strength: via a weight attached to a single group of participants' ankles. The provision of an ankle
6 weight should increase proprioceptive feedback strength by increasing musculotendinous
7 mechanoreceptor sensitivity (Bullock-Saxton, Wong, & Hogan, 2001; Suprak, Ostering, Donkelaar,
8 & Karduna, 2007). Results within the no-weight group demonstrated significantly lower ($p = 0.05$)
9 CE values when adopting an internal focus of attention second. Additionally, the weight group
10 demonstrated less endpoint CE when adopting an internal compared to an external focus.
11 Concurrently, across both weight-groups, an internal focus yielded more efficient muscle activation
12 compared to an external focus, and the shape of internal and external variability profiles were again
13 indicative of enhanced planning mechanisms under an internal focus.

14 In sum, our findings provide strong support to the notion that focus of attention-based
15 performance differences originate within offline movement planning for non-continuous tasks.
16 Additionally, our results support the notion of facilitative somaesthetic awareness and that an internal
17 focus congruent with task demands can benefit performance and efficiency. This finding makes
18 logical sense when one considers an external focus also has to be congruent with the intended external
19 movement outcome to facilitate optimal performance (e.g. focusing on the dart-board when the task
20 requires the dart-board to be hit) (Land, Tenenbaum, Ward, & Marquardt, 2013; Russell, Porter, &
21 Campbell, 2014). Similarly, Pelleck and Passmore (2017) show that when novice golfers adopted an
22 internal focus more closely related to a putting task, where there was a clear external outcome demand
23 and proprioceptive salience was arguably low, a number of performance variables suffered including
24 accuracy, EMG and movement kinematics. It is possible that had the external focus direction within
25 experiment 1 and 2 been directed towards the target as opposed to the cursor itself, task demands may

1 have been more congruent with an external focus and thus, it could be argued that we would have
2 seen a benefit of an external focus in this instance. However, the authors wanted to maintain
3 comparability between internal and external instructions to avoid a confound as per recommendations
4 from Wulf (2013).

5 However, it should be noted that the current study is not the first to investigate focus of
6 attention effects within tasks featuring high proprioceptive demands, but is the first with the explicit
7 aim of investigating internal focus of attention and task congruence. Limitations of prior studies
8 which prohibit the generalisation of their results to this research question include: task instructions
9 muddling an internal and external focus (Lohse et al., 2011; Lohse, 2012); internal focus instructions
10 that may not have been congruent with the external task demands / may only have directed attention
11 to a small subset of task-relevant proprioception (Land et al., 2013; Makaruk, Porter, & Makaruk,
12 2013; Sherwood, Lohse, & Healy, 2014); and tasks which were primarily dependent on online motor
13 corrections (Schlesinger, Porter, & Russell, 2013). It is important to highlight that despite
14 proprioception's arguably heightened pertinence in force production tasks, prior studies adopting this
15 approach have shown some converse results to that of the current research in target-directed aiming
16 tasks (e.g. Freedman, Caligiuri, Wulf, & Robin, 2007). We argue that the simplistic nature of these
17 tasks is a likely contributor to this. In these instances, task simplicity would have meant reduced
18 availability of proprioceptive information to enhance planning and thus, no benefits from an internal
19 focus.

20 **Conclusion.**

21 Theoretical implications derived from attentional focus literature advocate a perpetual
22 external focus for optimal movement execution, but this is incompatible with promotion of widely
23 used process goals and external/kinaesthetic imagery for practitioners. The current findings refute
24 the rigidity of the constrained action hypothesis and provide evidence that an internal focus can
25 facilitate superior performance and efficiency over an external focus when congruent with task

1 demands. This has strong implications for sports or tasks where proprioceptive salience is high,
2 such as diving, artistic gymnastics or weightlifting. Where traditional attentional focus literature
3 would advocate external instructions and feedback within these tasks (see Wulf, 2013 for a review)
4 e.g. a focus towards the surface of the water, support surface or bar respectively, the current
5 findings would suggest a focus on the body movements themselves. In line with the principles
6 underlying specificity theory (Proteau, 1992), sources of afferent information most useful to
7 performance execution are typically prioritised during processing. Thus, adopting an internal focus
8 within these sports should enhance congruence between the ‘instructions and feedback provided’
9 and the ‘availability of pertinent afferent information for task execution’, which is largely
10 proprioceptive in nature within these sports (see Figure 6 for sporting examples with varying
11 degrees of pertinence of proprioceptive and visual information for task execution). We suggest
12 internal instructions and feedback for tasks high in pertinence of proprioceptive information but low
13 in pertinence of visual information and external instructions and feedback for tasks low in
14 pertinence of proprioceptive information but high in pertinence of visual information. With this in
15 mind, it is therefore not a surprise that there seems more robust evidence for benefits of an external
16 compared to internal focus when most sports / tasks rely heavily on visual information for task
17 success (e.g. towards a ball or target). Clearly not all tasks can be classified as exclusively high or
18 low in pertinence of proprioceptive and visual information for task execution. Thus, we would
19 suggest that this works on a continuum basis with some sports likely benefitting from both forms of
20 instructions and feedback in different situations. This is in line with aforementioned arguments
21 made by Collins et al. (2015) and Lawrence et al. (2011) discussing nuances of attentional focus
22 instructions dependent on instructional familiarisation, task relevance and salience of movement
23 effects for task execution.

24 The present experiments also provide compelling evidence that attentional focus effects
25 manifest within offline movement planning for non-continuous tasks. This may have practical

1 implications for performance under pressure where athletes are more likely to adopt strategies (such
2 as an internal focus in proprioceptive tasks) to improve movement planning as a reaction to pressure
3 inhibiting the effectiveness of error corrections made during a movement (see Allsop, Lawrence,
4 Gray & Khan, 2017). By focusing on the body, findings suggest a shift in importance to offline
5 planning processes, which subsequently should also inhibit any decrements in response
6 programming under pressure.

7 -----
8 Insert Figure 6 here
9 -----

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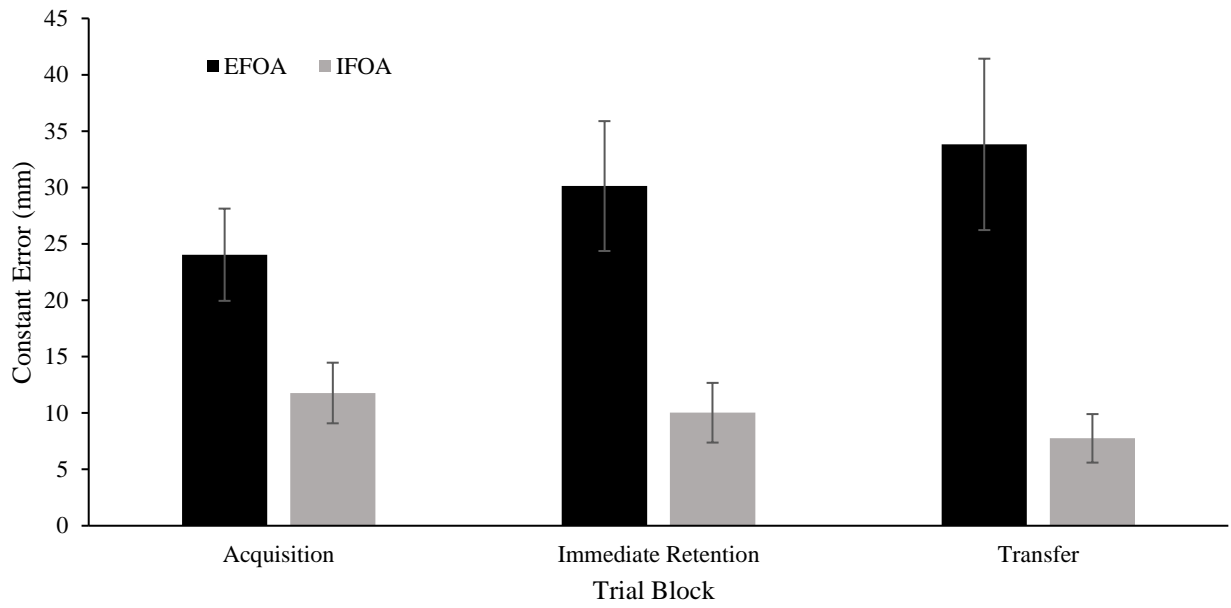
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Figure 1. Experiment 1. The task was a target-directed aiming movement, performed using a handheld stylus on a digitising tablet whereby the X/Y movement of the stylus on the tablet plane corresponded to the X/Y movement of the cursor on the monitor plane. Participants were required to move the cursor from the start position to one of three targets as quickly and accurately as possible.



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2 Figure 2. Experiment 1. External and internal group means (± 1 SEM) endpoint amplitude CE at
 3 acquisition, immediate retention, and transfer.

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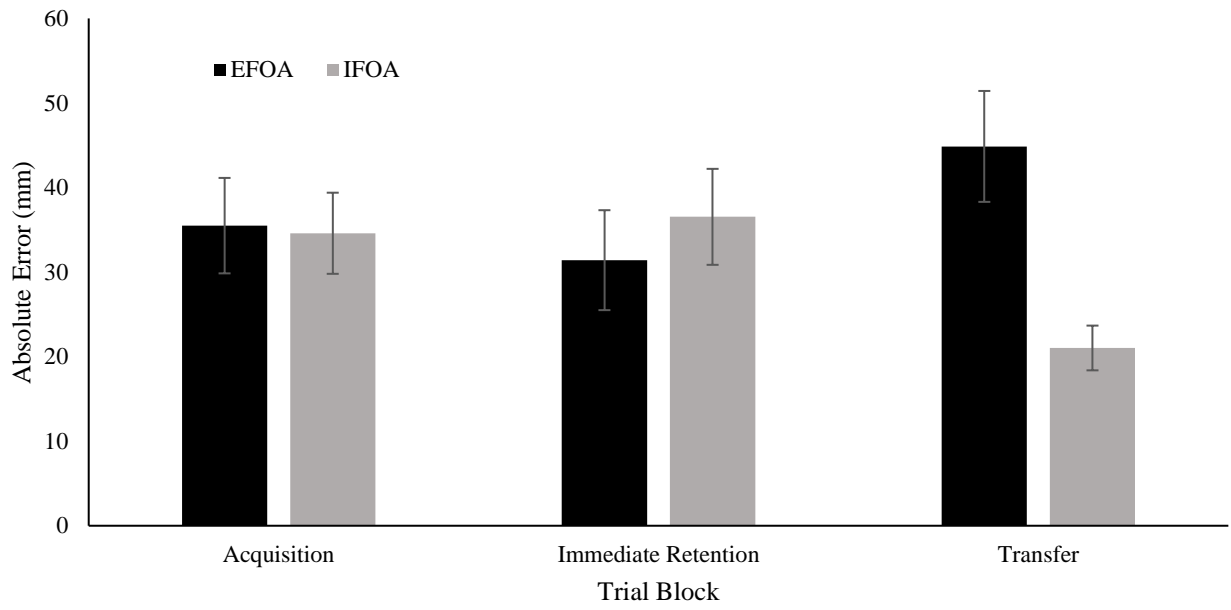
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2 Figure 3. Experiment 2. External and internal group means (± 1 SEM) endpoint amplitude AE at
3 acquisition, immediate retention, and transfer.
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2 Figure 4. Experiment 3. This was a leg-extension task whereby participants had to extend their leg
3 from a start position to a target position. Participants were required to reproduce a pre-encoded
4 target position as accurately as possible.

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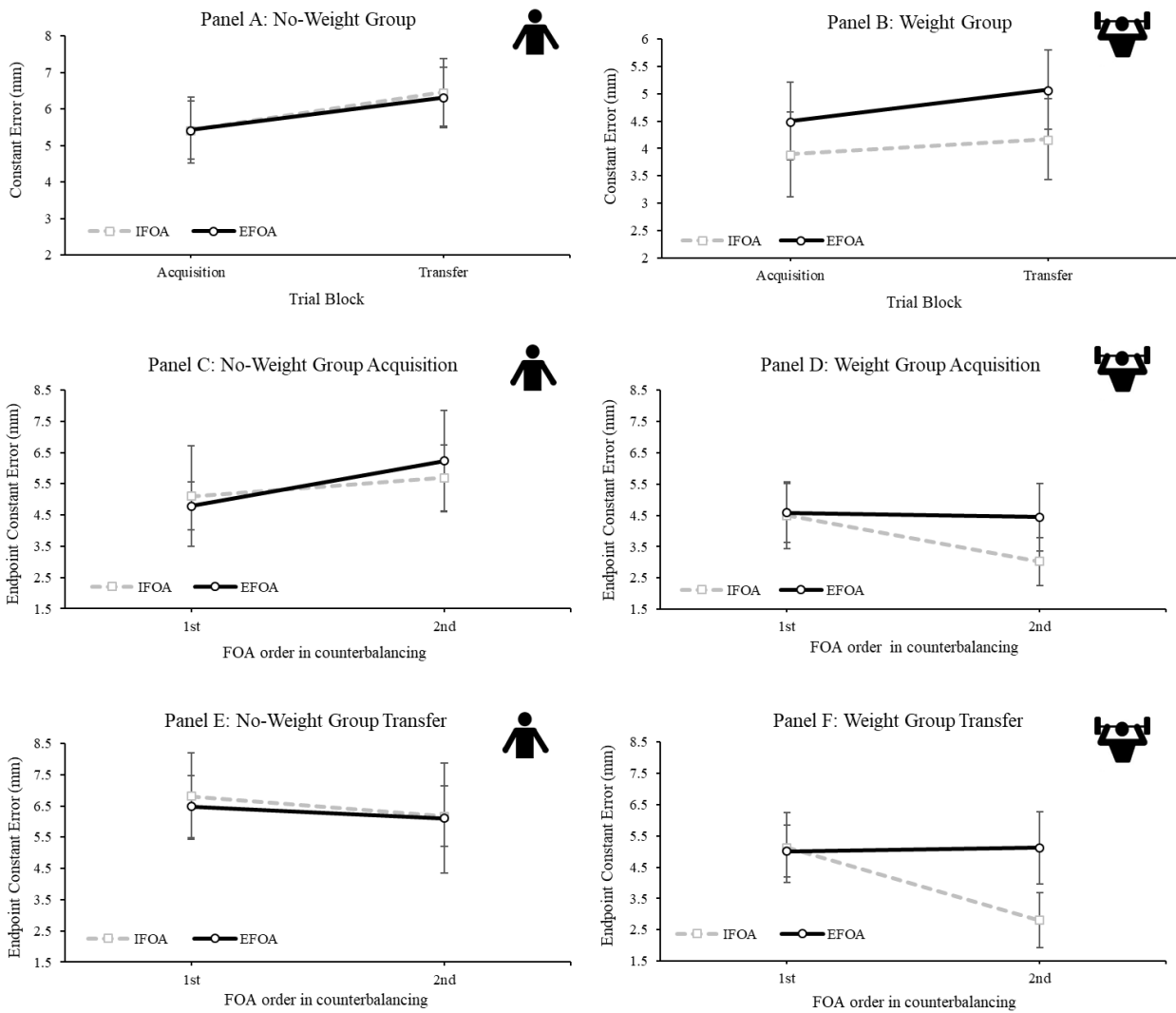
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2 Figure 5. Experiment 3. Panel A and B show CE for the internal and external focus conditions at
 3 acquisition and transfer for the no-weight and weight groups, respectively. Panels C, D, E and F
 4 show CE for each focus of attention when they appear as the first (i.e., initial) focus of attention in
 5 the counterbalanced order, and when they occur second. Panels C and E display the no-weight
 6 group's acquisition and transfer, respectively. Panels D and F display the weight group's acquisition
 7 and transfer, respectively. Error bars equal +/- 1 standard error.

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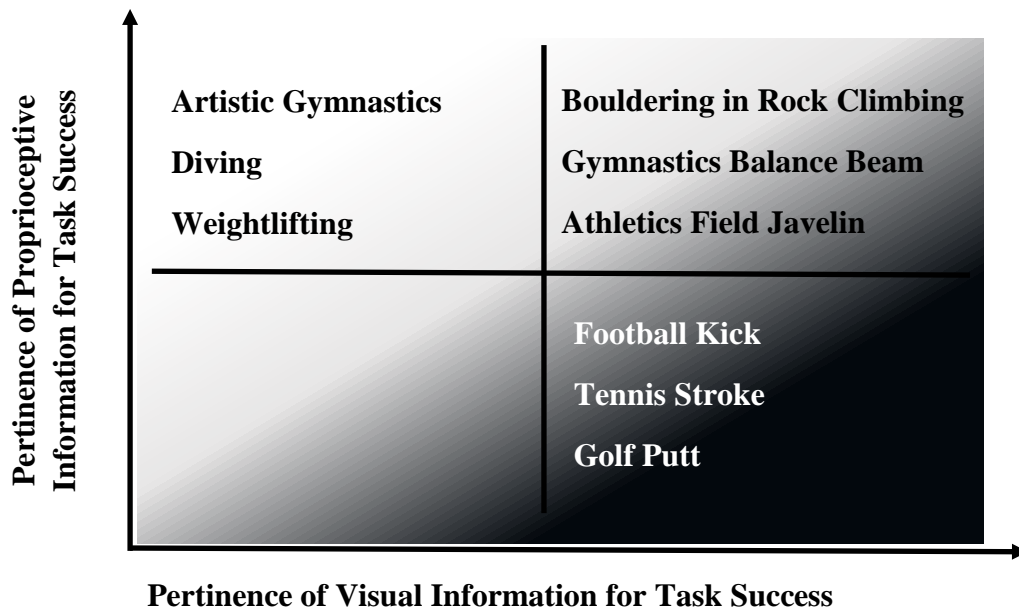


Figure 6. The above image categorises example sports based on the pertinence of proprioceptive and visual afferent information for successful task execution. Based on the findings, the authors would advocate internal instructions and feedback for tasks high in pertinence of proprioceptive information but low in pertinence of visual information (highlighted in lighter background). For tasks low in pertinence of proprioceptive information but high in pertinence of visual information (highlighted in darker background) we would advocate external instructions and feedback.

1 Table 1
 2 Descriptives and statistical results of experiment 1 omnibus analysis.

Table 1 (A): Descriptives of outcome performance

Component	Focus of attention	Trial Block	CE	AE	VE
Amplitude	External	Acquisition	24.04 (18.29)	26.08 (16.79)	16.67 (6.52)
		Retention	30.13 (25.76)	31.78 (25.75)	14.76 (12.27)
		Transfer	33.83 (33.99)	36.09 (32.62)	16.19 (8.85)
	Internal	Acquisition	11.77 (12.03)	14.17 (10.94)	11.24 (4.10)
		Retention	10.02 (11.84)	12.16 (11.05)	9.04 (2.38)
		Transfer	7.75 (9.62)	10.66 (8.20)	9.89 (3.99)
Directional	External	Acquisition	.512 (1.32)	6.78 (1.58)	8.41 (2.04)
		Retention	-0.96 (3.44)	6.76 (3.10)	8.04 (3.73)
		Transfer	-1.14 (5.09)	8.56 (3.75)	10.17 (3.73)
	Internal	Acquisition	.42 (3.44)	6.34 (3.03)	7.98 (3.39)
		Retention	-.23 (2.94)	6.06 (2.46)	7.76 (3.09)
		Transfer	-.33 (3.94)	6.69 (2.73)	8.76 (3.00)

Table 1 (B): Statistics of outcome performance

Component	Effect	CE	AE	VE
Amplitude	2 FOA x 3 Trial Block Interaction	$F_{1,27,48,27} = 3.93, p = .044, \eta^2 = .09^{**}$	$F_{1,40,53,23} = 3.89, p = .040, \eta^2 = .09^{**}$	$F_{1,30,64,08} = .076, p = .900, \eta^2 = .002$
	FOA Main Effect	$F_{1,38} = 11.15, p = .002, \eta^2 = .23^{**}$	$F_{1,38} = 11.72, p = .001, \eta^2 = .24^{**}$	$F_{1,38} = 10.04, p = .003, \eta^2 = .21^{**}$
	Trial Block Main Effect	$F_{1,27,48,27} = .74, p = .481, \eta^2 = .02$	$F_{1,40,53,23} = .902, p = .379, \eta^2 = .02$	$F_{1,30,64,08} = 1.58, p = .217, \eta^2 = .04$
Directional	2 FOA x 3 Trial Block Interaction	$F_{1,56,59,40} = .39, p = .631, \eta^2 = .01$	$F_{1,45,55,14} = 1.78, p = .185, \eta^2 = .05$	$F_{2,76} = .54, p = .586, \eta^2 = .01$
	FOA Main Effect	$F_{1,38} = .45, p = .504, \eta^2 = .01$	$F_{1,38} = .169, p = .202, \eta^2 = .04$	$F_{1,38} = 1.04, p = .314, \eta^2 = .03$
	Trial Block Main Effect	$F_{1,56,59,40} = 2.63, p = .093, \eta^2 = .07$	$F_{1,45,55,14} = 5.38, p = .014, \eta^2 = .12^{**}$	$F_{2,76} = 5.95, p = .004, \eta^2 = .14^{**}$

Table 1 (C): Descriptives of variability for planning and control contributions

Component	Focus of attention	Trial Block	VE at PkA	VE at PkV	VE at PkNA	VE at Endpoint
Amplitude	External	Acquisition	12.23 (4.62)	20.39 (4.75)	23.03 (4.83)	16.67 (6.52)
		Retention	12.95 (4.47)	19.09 (6.37)	21.25 (10.72)	14.76 (12.27)
		Transfer	15.45 (4.92)	22.28 (5.74)	22.01 (6.03)	16.19 (8.85)
	Internal	Acquisition	8.91 (3.32)	14.85 (2.76)	19.77 (4.14)	11.24 (4.10)
		Retention	8.03 (2.63)	13.98 (2.91)	16.53 (2.61)	9.04 (2.38)
		Transfer	11.83 (6.53)	16.14 (3.77)	18.20 (5.26)	9.89 (3.99)
Directional	External	Acquisition	3.73 (.78)	5.42 (1.26)	6.93 (1.60)	8.41 (2.04)
		Retention	3.53 (1.23)	5.15 (1.87)	6.51 (2.66)	8.04 (3.73)
		Transfer	3.98 (1.05)	6.11 (1.74)	8.27 (2.73)	10.17 (3.73)
	Internal	Acquisition	3.56 (1.02)	5.24 (1.66)	6.86 (2.33)	7.98 (3.39)
		Retention	3.17 (1.14)	4.71 (1.57)	6.07 (1.84)	7.47 (2.35)
		Transfer	3.76 (1.09)	5.84 (1.61)	7.47 (2.27)	8.76 (3.00)

Table 1 (D): Statistics of variability for planning and control contributions

Offline Planning					
Component	Effect	VE at PkA and PkV	Component	Effect	VE at 25% Movement Dist.
Amplitude	2 FOA x 3 Trial Block x 2 Marker	$F_{1,76} = .84, p = .438, \eta^2 = .02$	Directional	2 FOA x 3 Trial Block	$F_{2,76} = .20, p = .816, \eta^2 = .05$
	2 FOA x 3 Trial Block	$F_{2,76} = 1.93, p = .879, \eta^2 < .01$		FOA Main Effect	$F_{2,76} = .79, p = .380, \eta^2 = .02$
	2 FOA x 2 Marker	$F_{1,38} = 1.27, p = .267, \eta^2 = .03$		Trial Block Main Effect	$F_{2,76} = 5.30, p = .007, \eta^2 = .12^{**}$
	3 Trial Block x 2 Marker	$F_{1,76} = 1.18, p = .313, \eta^2 = .03$			
	FOA Main Effect	$F_{1,38} = 30.62, p < .001, \eta^2 = .45^{**}$			
	Trial Block Main Effect	$F_{2,76} = 12.66, p < .001, \eta^2 = .25^{**}$			
	Marker Main Effect	$F_{1,38} = 72.35, p < .001, \eta^2 = .66^{**}$			
Online Control					
Component	Effect	VE at PkV, PkNA, and endpoint	Component	Effect	VE at 75 and 100% Movement Dist.
Amplitude	2 FOA x 3 Trial Block x 3 Markers	$F_{1,24,123,08} = .22, p = .895, \eta^2 = .01$	Directional	2 FOA x 3 Trial Block x 2 Distance	$F_{2,76} = .56, p = .58, \eta^2 = .01$
	2 FOA x 3 Trial Block	$F_{2,76} = .14, p = .870, \eta^2 < .01$		2 FOA x 3 Trial Block	$F_{2,76} = .507, p = .604, \eta^2 = .01$
	2 FOA x 2 Marker	$F_{2,76} = .80, p = .455, \eta^2 = .02$		2 FOA x 2 Distance	$F_{1,38} = 1.33, p = .256, \eta^2 = .03$
	3 Trial Block x 2 Marker	$F_{3,24,123,08} = 1.67, p = .173, \eta^2 = .04$		3 Trial Block x 2 Distance	$F_{2,76} = .84, p = .437, \eta^2 = .02$
	FOA Main Effect	$F_{138} = 16.80, p < .001, \eta^2 = .31^{**}$		FOA Main Effect	$F_{1,38} = .86, p = .359, \eta^2 = .02$
	Trial Block Main Effect	$F_{2,76} = 5.02, p = .001, \eta^2 = .12^{**}$		Trial Block Main Effect	$F_{2,76} = 7.36, p = .001, \eta^2 = .16^{**}$
	Marker Main Effect	$F_{2,76} = 39.93, p < .001, \eta^2 = .51^{**}$		Distance Main Effect	$F_{1,38} = 86.66, p < .001, \eta^2 = .70^{**}$

* $p < .052$. ** $p < .05$.

1 Table 2
 2 Descriptives and statistical results of experiment 2 omnibus analysis.

Table 2 (A): Descriptives of outcome performance

Component	Focus of attention	Trial Block	CE	AE	VE
Amplitude	External	Acquisition	-7.30 (40.71)	35.49 (25.24)	23.49 (7.44)
		Retention	24.03 (29.36)	31.41 (26.42)	17.76 (8.48)
		Transfer	-35.17 (38.68)	44.86 (29.33)	26.90 (25.77)
	Internal	Acquisition	-3.07 (40.11)	34.59 (21.45)	24.12 (7.52)
		Retention	30.71 (29.77)	36.53 (25.38)	18.36 (9.70)
		Transfer	9.12 (18.50)	21.02 (11.83)	9.78 (5.43)
Directional	External	Acquisition	.92 (10.91)	36.35 (22.28)	42.81 (28.09)
		Retention	-3.31 (12.79)	31.47 (24.02)	35.15 (30.20)
		Transfer	2.91 (14.63)	34.66 (23.96)	39.37 (30.21)
	Internal	Acquisition	-3.03 (5.94)	22.32 (10.13)	27.13 (12.26)
		Retention	-5.42 (10.96)	19.33 (12.03)	22.04 (13.63)
		Transfer	-2.45 (12.55)	22.06 (15.71)	25.21 (17.37)

Table 2 (B): Statistics of outcome performance

Component	Effect	CE	AE	VE
Amplitude	2 FOA x 3 Trial Block Interaction	$F_{1,38,51.82} = 1.489, p = .232, \eta^2 = .04$	$F_{1,37,51.90} = 8.54, p = .002, \eta^2 = .18^{**}$	$F_{1,49,56.51} = 2.54, p = .103, \eta^2 = .06$
	FOA Main Effect	$F_{1,38} = 14.29, p = .001, \eta^2 = .27^{**}$	$F_{1,38} = 1.09, p = .302, \eta^2 = .03$	$F_{1,38} = .29, p = .592, \eta^2 = .008$
	Trial Block Main Effect	$F_{1,38,51.82} = 25.301, p < .001, \eta^2 = .40^{**}$	$F_{1,37,51.90} = .16, p = .767, \eta^2 = .004$	$F_{1,49,56.51} = 5.08, p = .016, \eta^2 = .12^{**}$
Directional	2 FOA x 3 Trial Block Interaction	$F_{1,59,60.282} = .16, p = .851, \eta^2 = .004$	$F_{1,63,61.90} = .25, p = .732, \eta^2 = .007$	$F_{1,61,61.20} = .346, p = .708, \eta^2 = .009$
	FOA Main Effect	$F_{1,38} = 2.07, p = .159, \eta^2 = .05$	$F_{1,38} = 5.04, p = .031, \eta^2 = .12^{**}$	$F_{1,38} = 4.02, p = .052, \eta^2 = .10^*$
	Trial Block Main Effect	$F_{1,59,60.28} = 2.77, p = .082, \eta^2 = .07$	$F_{1,63,61.90} = 4.37, p = .023, \eta^2 = .10^{**}$	$F_{1,61,61.20} = 8.46, p = .001, \eta^2 = .18^{**}$

Table 2 (C): Descriptives of variability for planning and control contributions

Component	Focus of attention	Trial Block	VE at PkA	VE at PkV	VE at PkNA	VE at Endpoint
Amplitude	External	Acquisition	12.50 (8.08)	17.11 (3.36)	25.09 (4.23)	23.49 (7.44)
		Retention	11.08 (6.44)	15.27 (5.28)	21.00 (9.31)	17.76 (8.48)
		Transfer	15.00 (14.03)	18.07 (11.08)	28.23 (23.22)	26.90 (25.80)
	Internal	Acquisition	14.25 (5.76)	20.21 (4.28)	27.56 (8.27)	24.76 (7.52)
		Retention	11.77 (4.29)	17.12 (4.80)	22.93 (9.25)	18.36 (9.70)
		Transfer	13.06 (4.88)	18.73 (4.88)	23.29 (6.50)	19.78 (5.43)
Directional	External	Acquisition	11.67 (6.74)	22.84 (14.59)	34.36 (23.02)	42.81 (28.09)
		Retention	10.02 (8.00)	19.20 (17.23)	28.94 (26.83)	35.15 (30.20)
		Transfer	12.09 (9.40)	23.89 (21.07)	34.58 (29.13)	39.37 (30.21)
	Internal	Acquisition	7.06 (2.99)	12.89 (5.97)	19.87 (9.53)	27.13 (12.26)
		Retention	5.61 (2.84)	10.50 (6.21)	16.06 (10.20)	22.04 (13.63)
		Transfer	6.37 (3.50)	11.66 (7.43)	17.989 (12.71)	25.21 (17.37)

Table 2 (D): Statistics of variability for planning and control contributions

Offline Planning					
Component	Effect	VE at PkA and PkV	Component	Effect	VE at 25% Movement Dist.
Amplitude	2 FOA x 3 Trial Block x 2 Marker	$F_{2,36} = .22, p = .802, \eta^2 = .01$	Directional	2 FOA x 3 Trial Block	$F_{1,49,56.55} = 1.18, p = .303, \eta^2 = .03$
	2 FOA x 3 Trial Block	$F_{1,44,33.32} = 2.00, p = .157, \eta^2 = .05$		FOA Main Effect	$F_{1,38} = 6.91, p = .012, \eta^2 = .15^{**}$
	2 FOA x 2 Marker	$F_{1,38} = .79, p = .380, \eta^2 = .02$		Trial Block Main Effect	$F_{1,49,56.55} = 6.94, p = .005, \eta^2 = .15^{**}$
	3 Trial Block x 2 Marker	$F_{2,36} = .30, p = .740, \eta^2 = .01$			
	FOA Main Effect	$F_{1,38} = .36, p = .552, \eta^2 = .01$			
	Trial Block Main Effect	$F_{1,44,33.32} = 5.95, p = .010, \eta^2 = .14^{**}$			
	Marker Main Effect	$F_{1,38} = 25.18, p < .001, \eta^2 = .40^{**}$			
Online Control					
Component	Effect	VE at PkV, PkNA, and endpoint	Component	Effect	VE at 75 and 100% Movement Dist.
Amplitude	2 FOA x 3 Trial Block x 3 Markers	$F_{2,31,87.81} = 1.82, p = .162, \eta^2 = .05$	Directional	2 FOA x 3 Trial Block x 2 Distance	$F_{1,31,52.12} = 4.35, p = .032, \eta^2 = .10$
	2 FOA x 3 Trial Block	$F_{1,32,50.15} = 2.22, p = .136, \eta^2 = .06$		2 FOA x 3 Trial Block	$F_{1,59,60.21} = .39, p = .630, \eta^2 = .01$
	2 FOA x 2 Marker	$F_{1,46,50.54} = 1.71, p = .196, \eta^2 = .04$		2 FOA x 2 Distance	$F_{1,38} = .06, p = .810, \eta^2 < .01$
	3 Trial Block x 2 Marker	$F_{2,31,87.81} = 1.80, p = .165, \eta^2 = .05$		3 Trial Block x 2 Distance	$F_{1,31,49.71} = 5.34, p = .017, \eta^2 = .12^{**}$
	FOA Main Effect	$F_{1,38} < .01, p = .993, \eta^2 < .01$		FOA Main Effect	$F_{1,38} = 4.77, p = .035, \eta^2 = .11^{**}$
	Trial Block Main Effect	$F_{1,32,50.15} = 4.47, p = .030, \eta^2 = .11^{**}$		Trial Block Main Effect	$F_{1,59,60.21} = 7.28, p = .003, \eta^2 = .16^{**}$
	Marker Main Effect	$F_{1,46,50.54} = 25.23, p < .001, \eta^2 = .40^{**}$		Distance Main Effect	$F_{1,38} = 92.82, p < .001, \eta^2 = .71^{**}$

* $p < .052$. ** $p < .05$.

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1 Table 3
 2 Descriptives and statistical results of experiment 3 omnibus analysis.

Table 3 (A): Descriptives of outcome performance

Ankle	Focus of attention	Order	Trial Block	CE	AE	VE	
Weighted	External	before an internal FOA	Acquisition	4.58 (2.47)	5.13 (2.28)	3.75 (1.29)	
			Transfer	5.01 (2.19)	5.26 (2.02)	3.57 (.67)	
		after an internal FOA	Acquisition	4.44 (3.42)	5.30 (2.64)	3.53 (.70)	
			Transfer	5.12 (2.19)	5.79 (3.01)	3.81 (1.19)	
		Internal	before an external FOA	Acquisition	4.50 (3.39)	5.34 (2.58)	3.39 (1.09)
				Transfer	5.12 (3.52)	5.86 (2.81)	4.05 (1.01)
	after an external FOA		Acquisition	3.02 (2.04)	4.19 (1.18)	3.76 (.71)	
			Transfer	2.80 (2.31)	3.80 (1.58)	3.49 (.95)	
	No-Weight	External	before an internal FOA	Acquisition	4.79 (2.41)	5.19 (1.99)	3.45 (.82)
				Transfer	6.49 (3.14)	6.82 (2.86)	4.17 (1.11)
			after an internal FOA	Acquisition	6.23 (4.60)	6.74 (4.02)	3.81 (.94)
				Transfer	6.11 (4.97)	6.58 (4.57)	3.93 (1.30)

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Table 3 (B): Statistics of outcome performance

Ankle	Effect	CE	AE	VE
Weighted	2 FOA x 2 Block x 2 Order Interaction	$F_{1,15} = .34, p = .567, \eta^2 = .02$	$F_{1,15} = .33, p = .575, \eta^2 = .02$	$F_{1,15} = .59, p = .456, \eta^2 = .04$
	2 FOA x 2 Trial Block Interaction	$F_{1,15} = .48, p = .501, \eta^2 = .03$	$F_{1,15} = .26, p = .616, \eta^2 = .02$	$F_{1,15} = .24, p = .631, \eta^2 = .02$
	2 FOA x 2 Order Interaction	$F_{1,15} = 4.74, p = .046, \eta^2 = .24^{**}$	$F_{1,15} = 3.17, p = .095, \eta^2 = .18$	$F_{1,15} = .05, p = .821, \eta^2 < .01$
	2 Block x 2 Order Interaction	$F_{1,15} = .44, p = .517, \eta^2 = .029$	$F_{1,15} = .81, p = .382, \eta^2 = .05$	$F_{1,15} = 2.86, p = .112, \eta^2 = .16$
	FOA Main Effect	$F_{1,15} = 4.45, p = .052, \eta^2 = .23^*$	$F_{1,15} = 2.64, p = .125, \eta^2 = .15$	$F_{1,15} < .01, p = .968, \eta^2 < .01$
	Trial Block Main Effect	$F_{1,15} = .83, p = .376, \eta^2 = .05$	$F_{1,15} = .29, p = .598, \eta^2 = .02$	$F_{1,15} = .38, p = .550, \eta^2 = .02$
	Order Main Effect	$F_{1,15} = .48, p = .498, \eta^2 = .03$	$F_{1,15} = .84, p = .374, \eta^2 = .05$	$F_{1,15} = .02, p = .891, \eta^2 < .01$
No-Weight	2 FOA x 2 Block x 2 Order Interaction	$F_{1,16} = 4.47, p = .051, \eta^2 = .22^*$	$F_{1,16} = 3.66, p = .074, \eta^2 = .17$	$F_{1,16} = .01, p = .912, \eta^2 < .01$
	2 FOA x 2 Trial Block Interaction	$F_{1,16} = .19, p = .671, \eta^2 = .01$	$F_{1,16} = .13, p = .723, \eta^2 = .01$	$F_{1,16} = .06, p = .808, \eta^2 < .01$
	2 FOA x 2 Order Interaction	$F_{1,16} = .20, p = .660, \eta^2 = .01$	$F_{1,16} = .07, p = .793, \eta^2 < .01$	$F_{1,16} = .18, p = .675, \eta^2 = .01$
	2 Block x 2 Order Interaction	$F_{1,16} = .01, p = .943, \eta^2 < .01$	$F_{1,16} = .49, p = .494, \eta^2 = .03$	$F_{1,16} = 4.02, p = .062, \eta^2 = .21$
	FOA Main Effect	$F_{1,16} = .15, p = .708, \eta^2 = .01$	$F_{1,16} = .06, p = .815, \eta^2 < .01$	$F_{1,16} < .01, p = .991, \eta^2 < .01$
	Trial Block Main Effect	$F_{1,16} = 5.73, p = .029, \eta^2 = .26^{**}$	$F_{1,16} = 5.81, p = .028, \eta^2 = .27^{**}$	$F_{1,16} = 8.36, p = .011, \eta^2 = .34^{**}$
	Order Main Effect	$F_{1,16} = .03, p = .864, \eta^2 < .01$	$F_{1,16} = .137, p = .716, \eta^2 = .01$	$F_{1,16} < .01, p = .971, \eta^2 < .01$

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Table 3 (C): Descriptives of variability for planning and control contributions

Ankle	Focus of attention	Order	Trial Block	VE at PkA	VE at PkV	VE at PkNA	VE at Endpoint	
Weighted	External	before an internal FOA	Acquisition	1.62 (.50)	4.37 (.91)	7.26 (1.15)	7.49 (1.01)	
			Transfer	1.76 (.67)	5.56 (.69)	9.99 (1.05)	11.28 (1.10)	
		after an internal FOA	Acquisition	1.98 (.88)	4.16 (.68)	7.09 (.91)	7.64 (1.06)	
			Transfer	2.12 (.73)	6.03 (.83)	10.41 (1.39)	11.51 (1.62)	
		Internal	before an external FOA	Acquisition	2.19 (1.09)	4.63 (.65)	7.54 (1.01)	8.19 (.84)
				Transfer	2.50 (.80)	5.84 (.93)	10.03 (.98)	11.12 (1.28)
	after an external FOA		Acquisition	1.57 (.52)	4.26 (.80)	7.21 (1.36)	7.74 (1.15)	
			Transfer	1.45 (.51)	5.71 (.63)	9.98 (.97)	11.20 (1.22)	
	No-Weight	External	before an internal FOA	Acquisition	2.04 (.71)	4.57 (.71)	7.45 (.97)	7.52 (1.06)
				Transfer	2.28 (.57)	5.28 (.76)	9.21 (.63)	10.64 (1.23)
			after an internal FOA	Acquisition	1.72 (.90)	4.50 (.96)	7.40 (1.00)	8.15 (1.41)
				Transfer	1.88 (.63)	6.03 (.97)	10.78 (1.25)	12.05 (2.26)
Internal		before an external FOA	Acquisition	2.48 (1.81)	5.25 (1.34)	8.37 (1.45)	8.84 (1.51)	
			Transfer	2.36 (.79)	5.97 (1.14)	10.32 (1.30)	11.49 (1.73)	
	after an external FOA	Acquisition	1.78 (.72)	3.88 (.91)	6.90 (.68)	7.41 (1.17)		
		Transfer	1.71 (.79)	5.39 (.70)	9.41 (.91)	10.63 (1.38)		

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Table 3 (D): Descriptives of variability for planning and control contributions

Offline Planning			Online Control		
Ankle	Effect	VE at PkA and PkV	Ankle	Effect	VE at PkV, PkNA, and endpoint
Weighted	2 FOA x 2 Trial Block x 2 Marker x 2 Order	$F_{2,15} = 16.22, p = .001, \eta^2 = .52^{**}$	Weighted	2 FOA x 2 Trial Block x 3 Marker x 2 Order	$F_{2,30} = .16, p = .851, \eta^2 = .01$
	2 FOA x 2 Trial Block x 2 Marker	$F_{2,15} = .78, p = .391, \eta^2 = .05$		2 FOA x 2 Trial Block x 3 Marker	$F_{2,30} = 1.18, p = .322, \eta^2 = .07$
	2 FOA x 2 Marker x 2 Order	$F_{2,15} = 1.06, p = .319, \eta^2 = .07$		2 FOA x 3 Marker x 2 Order	$F_{2,30} = .06, p = .941, \eta^2 < .01$
	2 FOA x 2 Marker	$F_{2,15} = .02, p = .896, \eta^2 < .01$		2 FOA x 3 Marker	$F_{2,30} = .11, p = .895, \eta^2 = .01$
	2 FOA x 2 Trial Block x 2 Order	$F_{2,15} = .39, p = .542, \eta^2 = .03$		2 FOA x 2 Trial Block x 2 Order	$F_{1,15} = 2.12, p = .166, \eta^2 = .12$
	2 FOA x 2 Trial Block	$F_{2,15} = .37, p = .552, \eta^2 = .02$		2 FOA x 2 Trial Block	$F_{1,15} = 2.22, p = .157, \eta^2 = .13$
	2 FOA x 2 Order	$F_{2,15} = 2.17, p = .162, \eta^2 = .13$		2 FOA x 2 Order	$F_{1,15} = .02, p = .887, \eta^2 < .01$
	FOA Main Effect	$F_{2,15} = .44, p = .517, \eta^2 = .03$		FOA Main Effect	$F_{1,15} = .07, p = .795, \eta^2 = .01$

	Trial Block Main Effect	$F_{2, 15} = 66.17, p < .001, \eta^2 = .82^{**}$		Trial Block Main Effect	$F_{1, 15} = 331.93, p < .001, \eta^2 = .95^{**}$
	Marker Main Effect	$F_{2, 15} = 248.90, p < .001, \eta^2 = .94^{**}$		Marker Main Effect	$F_{1, 36, 20, 33} = 432.73, p < .001, \eta^2 = .97^{**}$
	Order Main Effect	$F_{2, 15} = 2.70, p = .121, \eta^2 = .15$		Order Main Effect	$F_{2, 30} = .28, p = .607, \eta^2 = .02$
No-Weight	2 FOA x 2 Trial Block x 2 Marker x 2 Order	$F_{2, 16} = 2.15, p = .162, \eta^2 = .12$	No-Weight	2 FOA x 2 Trial Block x 3 Marker x 2 Order	$F_{2, 32} = .80, p = .457, \eta^2 = .05$
	2 FOA x 2 Trial Block x 2 Marker	$F_{2, 16} = .26, p = .618, \eta^2 = .02$		2 FOA x 2 Trial Block x 3 Marker	$F_{2, 32} = 1.46, p = .248, \eta^2 = .08$
	2 FOA x 2 Marker x 2 Order	$F_{2, 16} = 1.08, p = .315, \eta^2 = .06$		2 FOA x 3 Marker x 2 Order	$F_{2, 32} = 1.02, p = .374, \eta^2 = .06$
	2 FOA x 2 Marker	$F_{2, 16} = .16, p = .691, \eta^2 = .01$		2 FOA x 3 Marker	$F_{2, 32} = .02, p = .984, \eta^2 < .01$
	2 FOA x 2 Trial Block x 2 Order	$F_{2, 16} = 4.99, p = .040, \eta^2 = .24^{**}$		2 FOA x 2 Trial Block x 2 Order	$F_{1, 16} = 10.62, p = .005, \eta^2 = .40^{**}$
	2 FOA x 2 Trial Block	$F_{2, 16} = .70, p = .415, \eta^2 = .04$		2 FOA x 2 Trial Block	$F_{1, 16} = 1.37, p = .258, \eta^2 = .08$
	2 FOA x 2 Order	$F_{2, 16} = 7.40, p = .015, \eta^2 = .32^{**}$		2 FOA x 2 Order	$F_{1, 16} = 2.58, p = .128, \eta^2 = .14$
	FOA Main Effect	$F_{2, 16} = .17, p = .682, \eta^2 = .01$		FOA Main Effect	$F_{1, 16} = .04, p = .853, \eta^2 < .01$
	Trial Block Main Effect	$F_{2, 16} = 14.87, p = .001, \eta^2 = .48^{**}$		Trial Block Main Effect	$F_{1, 16} = 117.18, p < .001, \eta^2 = .92^{**}$
	Marker Main Effect	$F_{2, 16} = 508.04, p < .001, \eta^2 = .97^{**}$		Marker Main Effect	$F_{1, 25, 20, 02} = 180.47, p < .001, \eta^2 = .92^{**}$
	Order Main Effect	$F_{2, 16} = 2.13, p = .164, \eta^2 = .12$		Order Main Effect	$F_{2, 32} = 6.27, p = .023, \eta^2 = .28^{**}$

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2 * $p < .052$. ** $p < .05$.

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