An interdisciplinary examination of attentional focus strategies used during running gait retraining

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Abstract

The aim was to investigate the biomechanical, physiological and perceptual responses to different motor learning strategies derived to elicit a flatter foot contact. Twenty-eight, rearfoot-striking recreational runners (age 24.9±2.8 years; body mass 78.8±13.6 kg; height 1.79±0.09 m) were matched by age, mass and height and assigned to one verbal cue group: internal focus of attention (IF), external focus of attention (EF) and a clinically derived condition (CLIN) incorporating an IF followed by an EF statement. Participants completed two treadmill runs at 10 $km \cdot h^{-1}$ for six minutes each: normal running (control) followed by the experimental condition (IF, EF or CLIN). Lower limb kinematics, oxygen consumption ($\dot{V}O_2$) and central and peripheral ratings of perceived exertion (RPE) were recorded for each run. Compared to the control condition, foot angle was reduced in the IF (difference=5.86°, d=2.58) and CLIN (difference=3.00°, d=1.31) conditions, but unchanged in the EF (difference=0.33°, d=0.14) condition, whilst greater knee flexion at initial contact in the EF and CLIN conditions was observed (difference=-5.19°, d=1.97; difference=-3.66°, d=1.39, respectively). A higher $\dot{V}O_2$ was observed in the CLIN condition (difference=-4.56 $ml \cdot kg^{-1} \cdot min^{-1}$, d=2.29), but unchanged in the IF (difference = -1.87 $ml \cdot kg^{-1} \cdot min^{-1}$, d=0.94) and EF conditions (difference=-0.37 $ml \cdot kg^{-1} \cdot min^{-1}$, d=0.19). All experimental conditions increased central and peripheral RPE (difference=-1.08, d=0.54 and difference=-2.39, d=1.33 respectively). Providing gait retraining instructions using an internally directed focus of attention was the most effective way to target specific changes in running kinematics, with no detrimental effect on physiological responses. Yet, perceptual effort responses increased regardless of the type of cue provided.

Key words: attentional focus, gait retraining, kinematics, oxygen consumption, perceived exertion

Introduction

Running gait retraining refers to providing instructions and/or feedback to an individual to alter their running biomechanics[1]. Specifically, it is the term used when biomechanically intervening to alter gait with a view to rehabilitate or prevent running-related injuries (RRI). Running gait retraining has been used to rehabilitate some of the most common overuse, lower limb RRI (e.g. anterior knee pain[2-4], chronic exertional compartment syndrome[5,6] and iliotibial band syndrome[7]). These rehabilitation strategies are required due to the high prevalence of RRIs, which have been reported in up to 80% of runners per annum[8]. Running gait retraining interventions have targeted several biomechanical variables that either have a theoretical link to, or empirical association with, the development of a RRI (e.g. high tibial accelerations and large, positive foot angles at initial contact). The premise of running gait retraining being that altering these biomechanical variables will reduce and/or re-distribute the associated lower limb mechanical load and alleviate injury symptoms.

Having a large, positive foot angle at initial contact is characterised by the heel being lower than the toes at initial ground contact and has been linked to overuse RRI[9]. Whilst foot angle lies on a continuum, research often categorises individuals into three 'foot strike patterns': rearfoot (heel contacting the ground first), midfoot (simultaneous ground contact of heel and ball of foot) and forefoot (ball of foot contacting the ground first) strikers. Altering foot angle to promote a flatter foot placement by lowering the forefoot (ball of the foot) elicits several biomechanical changes such as a reduction in stride length and increase in stride frequency[10], greater knee flexion at initial contact and reduced peak knee flexion during stance[11]. Furthermore, reducing foot angle redistributes the mechanical load associated with running from the knee to the ankle and calf musculotendon unit[12]. However, many studies use changes in ankle dorsiflexion to denote altered foot strike patterns (e.g., Roper et al.[2]), when in fact this represents changes in the shank, foot or both segmental angles. This may have led to misinterpretations regarding the effect of foot strike pattern changes. Nevertheless, the high prevalence of knee RRI[8] and the redistribution of mechanical load from the knee to the ankle has led to studies specifically targeting changes in foot angle during running gait retraining[2,4].

Various gait retraining interventions have been proposed, with many drawing upon the motor learning literature to develop their protocols, for example, feedback[13,14] and verbal cues[5,15]. The use of verbal cues is a particularly promising avenue of investigation as the provision of verbal instructions can help focus an individual's attention to specific features of their environment or the activity itself. Wulf and associates[16,17] have produced an extensive program of research that addresses the question of what performers should focus their attention on when re-/learning motor skills. Wulf has consistently demonstrated that instructions promoting a focus upon bodily movements, an internal focus of attention, are relatively ineffective compared to instructions that promote a focus on the effect of the movement on the environment or apparatus, an external focus of attention. The benefit of adopting an external focus resides in the promotion of automaticity of task execution. In contrast, an internal focus disrupts motor coordination by encouraging conscious control of movements and disrupting automaticity[17].

Several studies that have examined gait retraining have attempted to use verbal instructions that manipulate participants' attentional focus. In line with Wulf's model, Chow, Woo and Koh[18] predicted that an external focus of attention would facilitate a more effective transition from a rearfoot strike to forefoot strike pattern. Chow et al.[18] found that both types of instruction were beneficial in modifying foot strike patterns. However, Chow et al.'s[18] external focus cue was problematic in that they asked participants in this condition to "Strike your foot" in line with a virtual line that was projected onto the treadmill. The use of the word 'foot' may well have engendered at least a partial internal focus, confounding their results. Others have used mainly internally focused instructions to successfully modify a rearfoot strike to a forefoot strike. For example, Roper at al.[2] asked participants to "run on your toes" and/or "run on the balls of your feet" and successfully reduced ankle dorsiflexion and knee pain across eight training sessions. Others have asked participants to use a mix of internal and external focus cues[19], an approach also employed in clinical practice[20]. Consequently, no studies to date have directly compared the effectiveness of an internal focus cue versus an external focus cue to modify foot angle at initial contact ('footstrike'). Wulf and Prinz's[17] constrained action hypothesis would predict that instructions that focused participants' attention externally would be more effective in modifying rearfoot strike patterns when compared with instructions that are internally focused.

In addition to the disruption of automatic motor processes when altering running gait, there are also metabolic costs. Biomechanical and physiological studies have shown that acute changes to running gait typically increase submaximal oxygen consumption ($\dot{V}O_2$; see Moore[21] for a review), possibly due to the disruption of an individual's self-optimised running gait[22]. In particular, acutely changing from a rearfoot strike to a flatter foot contact increases $\dot{V}O_2$whereas, going from a flat foot contact to a rearfoot strike has a negligibile effect on $\dot{V}O_2$ [21]. However, these costs may not be pervasive as a series of studies conducted by Schücker and colleagues[23-26] found that an external focus of attention, viewing a video clip, resulted in reduced $\dot{V}O_2$ compared to internal focus of attention cues (e.g. "concentrate on the running movement" or "concentrate on breathing"). It is however important to note that the cues utilised in these studies were not designed to effect movement change but rather required participants to simply alter their focus. In addition, the absence of a control condition in several of these studies means there is limited understanding regarding the effects of the cues compared to habitual running.

Other physiological and perceptual indices such as heart rate, blood lactate levels and ratings of perceived exertion (RPE) have consistently produced null effects in studies examining attentional focus, even though $\dot{V}O_2$ changes have been observed. This is contrary to biomechanical and physiological studies that find consistent economical changes reflected in $\dot{V}O_2$, heart rate and RPE (e.g. Barnes & Janecke[27]). A more integrated approach that adopts biomechanical, physiological and perceptual indices to examine movement economy and a control condition may produce clearer results. In addition, no gait retraining studies to date have directly examined the predictions of Wulf and Prinz's[17] constrained action hypothesis as many authors have framed external and internal foci of attention within wider theoretical frameworks related to self-regulation and distraction e.g., Brick et al.[28]

In light of research findings and with the limitations noted above, the aim of this interdisciplinary study was to investigate the biomechanical, physiological and perceptual responses to different task-relevant attentional focus strategies created to elicit a flatter foot angle at initial contact. It was hypothesised that attentional focus manipulated using verbal cues with an internal or external focus would both reduce foot angle compared to normal running, but that the effect would be more pronounced in the external focus condition. It was also hypothesised that using a clinically relevant cue, such as an internal followed by an external focus cue, would produce a larger response than an internal cue alone but the response would be less pronounced than the external focus condition. Additionally, biomechanical changes such as greater knee flexion and reduced stride length were expected with a flatter foot angle. We also predicted that changes elicited in the internal focus and clinically relevant conditions would result in less economical movement compared to normal running, while the external focus condition would have a more economical movement, as indexed by $\dot{V}O_2$, heart rate and RPE.

Methods

Participants

To determine sample size, an a priori power analysis based on previous research[10] was conducted using G*POWER 3.1 (Universitat Kiel, Germany). To achieve a large effect size, partial $\eta^2 = 0.43$ ($\alpha = 0.05$, $1 - \beta = 0.80$), a required sample size of 18 was derived. Thirty-eight recreational runners provided informed consent and were initially screened. Of these, 28 (females: n = 6; males = 22) were visually and mathematically identified as being habitual rearfoot strikers (age: 24.9 ± 2.8 years; body mass 78.8 ± 13.6 kg; height 1.79 ± 0.09 m; weekly running distance 14.5 ± 10.5 km). To mathematically determine foot angles that were categorised as a rearfoot strike the minimally detectable difference [$SE \times 1.96 \times \sqrt{2}$;[29]] from a flat foot was used [*M* angle: 3.2˚; *SE*: 1.6˚ [30]]. Subsequently, participants needed to produce a foot angle at initial contact that was ≥ 7.6˚. Once screened, participants were matched by age, mass, and height (Table 1) and assigned to one of three groups. All participants completed a Physical Activity Readiness Questionnaire, had been injury-free for the previous six months and were familiar with treadmill running. Ethical approval for the study was obtained from the institute's ethics committee.

Experimental Conditions

Three verbal cues were developed to create the following task-relevant conditions: internal focus of attention (IF), external focus of attention (EF) and a clinical (CLIN) verbal cue specifically derived from current clinical practice that was an IF cue followed by EF cue. Typically, clinical practice uses an EF verbal cue due to its association with improving sports performance and recent evidence showing the EF verbal cue "run quietly" was effective at reducing vertical impact force and ankle dorsiflexion at initial contact[15]. However, prior to the EF verbal cue, instructions are provided by the clinician to educate patients about the desired movement effect of the gait retraining session, which would be categorised as an IF verbal cue. Therefore, the IF verbal cue was "run with a flat foot", the EF verbal cue was "run quietly" and the CLIN verbal cue was "we are aiming to change foot strike, so run quietly". All verbal cues were developed based on relevant literature e.g., Diebal et al.[5]; Phan et al.[15], and discussions with clinical and biomechanical running specialists and two sport psychologists. The aim of each verbal cue was to promote a flatter foot at initial ground contact.

Procedures

Participants were informed that the purpose of the study was to examine human responses to verbal instructions. No specific reference was made to foot strike (or foot angle) to avoid influencing behaviour or focus of attention. Additionally, if participants enquired whether they were responding correctly, they were told that there was no 'correct' response and that they should respond in a way that felt comfortable/natural for them. Participants visited the laboratory once to complete two treadmill runs at 10 $km \cdot h^{-1}$; a normal, habitual running condition (control) followed by one of the experimental conditions (IF, EF or CLIN). Before data collection, a five minute treadmill warm-up at a self-selected velocity was completed. Each treadmill run lasted six minutes and a five-minute rest period was provided between runs. During each run, kinematic data were captured at 200 Hz for 15 seconds during the final two minutes using CODAmotion V6.79.3 (Charnwood Dynamics Ltd, Leicestershire, UK). Additionally, throughout the run, breath-by-breath respiratory data were recorded using an online gas analysis system (OxyconPro, Jaeger at Viasys Healthcare, Warwick, UK) and heart rate was measured using a wireless chest strap telemetry system (Polar H30; Kempele, Finland). Verbal cues were provided every 30s by the same individual for each participant. This time period represents approximately one cue every 40 strides [stride frequency of 1.3 Hz at 10 $km \cdot h^{-1}$ [31]] and was based upon similar methodology employed during a continuous motor task[24,32]. A stride was defined as consecutive, same foot ground contact events. Finally, central and peripheral ratings of perceived exertion (RPE) were recorded at the end of each run using Borg's 6 – 20 scale[33] and following cessation of the experimental condition, a manipulation check was completed to assess the degree to which participants focused on the instruction provided. For example, "To what extent were you focused on (*running quietly* or *running with a flat foot* or *aiming to change foot strike, so running quietly*) as you were running?" using a 5-point Likert scale (1 = *not at all*; to 5 = *very much so*).

Biomechanical data

Three-dimensional kinematic data of the left lower limb were recorded from superficial active markers affixed to greater trochanter, lateral epicondyle, lateral malleolus, calcaneus and 5^{th} metatarsal (Figure 1). Kinematic data were filtered using a low-pass Butterworth recursive filter and residual analysis was used to determine the cut-off frequency for each dimension (16, 16, and 17 Hz, for x, y, and z respectively). Within the coordinate system, x denotes medial-lateral, y denotes anterior-posterior and z denotes vertical. Three segment angles (foot, shank and thigh) along with two joint angles (knee and ankle) were determined in the sagittal plane. Foot angle was defined as the angle between the laboratory coordinate system (LCS) anterior-posterior, horizontal and the foot segment, represented by the vector between the heel and 5^{th} metatarsal. Shank angle was defined as the angle between the LCS vertical and the shank segment, represented by the vector between the lateral epicondyle and lateral malleolus. Thigh angle was defined as the angle between the LCS vertical and the thigh segment, represented by the vector between the greater trochanter and lateral epicondyle. The knee and ankle angles were defined as the angle between the thigh and shank segment vectors, and shank and foot segment vectors respectively (Figure 1). All dynamic angles were normalised to a static calibration trial, which was obtained prior to the first treadmill run. All angles were determined at initial contact, with peak knee and ankle angles during the stance phase (foot ground contact) also computed.

A set of criteria was used to detect initial foot contact and toe-off frames to minimise detection errors identified during pilot work using previous algorithms [34]. Initial contact was determined using the peak vertical jerk and/or anterior-posterior, horizontal velocity of either the heel or 5^{th} metatarsal marker. The horizontal velocity was required to be within 10% of the treadmill speed. To determine toe-off a local maxima vertical heel acceleration and/or a local minima of the 5^{th} metatarsal vertical jerk after a visible plateau in vertical heel acceleration were used. The knee angle waveform was used to verify the initial foot contact and toe-off frames due to its predictable, cyclical motion producing minima near relevant time points. Six consecutive stride cycles were used for each participant. Data loss for the lateral epicondyle occurred during the verbal cue conditions for three participants, therefore their thigh, knee and shank angles were omitted where necessary. The within-session reliability assessed using an intraclass correlation coefficient (ICC) for absolute agreement [(ICC(2,1)[29]] of motion analysis within our laboratory was found to have excellent agreement for foot angle at initial contact (ICC = 0.991).

Physiological and perceptual data

The running velocity was deemed to be submaximal for all participants during each condition based on the respiratory exchange ratio being < 1.0 between the fourth and sixth minute of running. Following this confirmation, mean $\dot{V}O_2$ and heart rate during the final two minutes of each run were computed. Both datasets were visually examined to confirm that participants were in a physiological steady-state, which was represented by a plateau. Any within-participant outliers for each condition (2 SD away from mean) were removed from the data prior to computing the mean $\dot{V}O_2$ and heart rate values for each participant.

Central RPE was adopted to assess perceptions of cardiovascular and ventilatory exertion, while peripheral RPE assessed perceived muscular effort in the lower limb. Each participant was read anchoring scripts to acquaint them with the RPE scale and the differentiation between central and peripheral RPE was emphasised prior to the testing procedures.

Statistical analysis

Means and standard deviations for all biomechanical variables were calculated for each running trial using all gait cycles, in addition to group means and standard deviations being calculated for all variables across participants. To test homogeneity of variance, the variance ratio was computed ($F = \frac{subgroup_{maxVariance}}{subgroup_{minVariance}}$). Standardised residuals were also computed and distributions were checked for normality. To assess the effect of the verbal cues a two-way mixed ANOVA (2 x 3; Condition [Control, Experimental) x Group [IF, EF, CLIN], with repeated measures on the Condition factor) was used. Post-hoc analyses using Tukey's HSD were conducted where necessary. To assess the magnitude of changes partial η^2 and Cohen's *d* effect sizes were determined, with 0.25 and 0.8 representing a large effect for each respectively.

Results

Biomechanical measures

Results revealed significant interactions for foot and knee angle at initial contact, and peak knee flexion (see Table 4 for a summary of the two-way ANOVA's and Table 2 for *M* and *SD's*). Specifically, follow-up Tukey HSD tests indicated that the foot angle at initial contact was reduced in the IF (d = 2.58, p < 0.001) and CLIN condition (d = 1.31, p = 0.049), meaning the foot was flatter compared to the control run, whereas no effect was seen for EF (d = 0.14, p = 0.998). All participants in the IF group reduced their foot angle, whilst only 78% did in the CLIN group (Figure 2). Nine participants (IF n = 5; CLIN n = 4) produced responses that were categorised as a flat foot strike (foot angle < 7.6˚). With regard to knee angle at initial contact, greater flexion was present for the EF (d = 1.97, p = 0.002) and CLIN conditions (d = 1.39, p = 0.047) but not the IF condition (d = 0.41, p = 0.915) compared to the control condition. Finally, for peak knee flexion, an EF increased peak knee flexion from control (d = 1.57, p = 0.022) but no change was observed for IF (d = 0.35, p = 0.952) or CLIN (d = 1.09, p = 0.199).

Main effects for Condition were observed for the shank, thigh and ankle angle at initial contact, in addition to stride frequency and stride length. The shank angle at initial contact did not reach significance in the post-hoc analysis. With regard to ankle angle at initial contact, the experimental conditions reduced ankle dorisflexion (d = 0.84, p = 0.003) whilst the thigh became less upright at initial contact (d = 0.79, p = 0.006) compared to the control. Finally, for stride frequency and stride length, a higher frequency (d = 0.90, p = 0.002) and shorter strides (d = 0.86, p = 0.002) were observed in the experimental condition (Figure 3). There were no observable interactions or main effects for peak ankle flexion (Table 2) or ground contact time (see Figure 2).

Physiological and perceptual measures

A significant interaction effect was observed for $\dot{V}O_2$, with Tukey HSD tests revealing an increase in $\dot{V}O_2$ in the CLIN condition (d = 2.29, $p < 0.001$) but no change in the IF (d = 0.94, p = 0.268) or EF condition (d = 0.19, p = 0.994; Figure 4) compared to the control run. In addition, there was a significant main effect of condition for heart rate, with the experimental conditions producing a higher heart rate than the control (d = 0.70, p = 0.012). A main effect of condition was also observed for both central RPE and peripheral RPE, with the experimental conditions producing higher ratings for central RPE (d = 0.54, p = 0.047) and peripheral RPE (d = 1.33, $p < 0.001$) compared to the control condition (Table 3).

Manipulation check

A one-way ANOVA conducted to establish whether there was a difference in verbal cue adherence between conditions was not significant, $F(2,27) = 0.457$, $p = 0.638$, with 96% (n = 27) of participants reporting an adherence score ≥ 4 and the final participant reporting a three.

Discussion

The aim of this study was to investigate the biomechanical, physiological and perceptual responses to different verbal cue strategies derived to elicit a flatter foot contact. Both the IF and CLIN cues successfully reduced foot angle at initial contact, whilst the EF and CLIN conditions increased knee angle at initial contact. With regard to physiological and perceptual indices, increases in $\dot{V}O_2$ were only shown in the CLIN condition, whilst providing verbal cues led to increases in heart rate and both central and peripheral RPE across the experimental conditions.

Our first hypothesis predicting a reduction in foot angle in the experimental conditions was partially supported. Both the IF and CLIN conditions elicited a flatter foot angle at ground contact. Contrary to our hypothesis and previous research[13,15,19], the EF cue to "run quietly" was not effective at producing a flatter foot angle. However, others have included visual biofeedback in the form of tibial acceleration or have actually used the verbal cue 'make your footfalls quieter'[19,35], which is similar to our CLIN condition, suggesting the internally directed part of the statement may be responsible for inducing change. While there is substantial evidence highlighting the advantages of an EF, there is a body of work that advocates the importance of an IF as a mediator of continuous improvement[36]. Specifically, it has been noted that when an individual needs to adjust or correct a skill, critical self-attention may in fact be necessary in order to facilitate change. This 'constructive conscious control'[36] allows an individual to refine habitual movement patterns and heighten kinesthetic awareness of the new, more efficient movement in order for it in turn, to become attenuated. It has also been noted that individuals who solely rely on focusing on the effects of one's actions (i.e., EF) are to some extent trusting that movements will change "themselves through unconscious trial and error or through eventual evolutionary adjustments"[37]. It may be that within the present study, the IF condition provided individuals with a degree of bodily awareness that allowed them to modify their movement, while those in the EF condition who were blind to the overall goal of the action, to elicit a flatter foot contact, had no kinesthetic reference point in order to effect change.

Further, between-participant variation in foot angle responses can be clearly observed (Figure 2), highlighting the role that participant cue interpretation may play during running gait retraining[38]. Importantly, the IF condition produced the most consistent set of foot angle and physiological responses (Figure 4) emphasising the potential importance of explicit instructions. Such instructions actively direct attention internally giving the individual a point of reference about process changes so that running gait may be modified. To our knowledge, this is the first study to show such a similarlity in mechanical and physiological responses due to earlier work neglecting to take an interdisciplinary perspective.

Interestingly, more proximal lower limb biomechanical adjustments were observed for the external cue, in particular greater knee flexion at initial contact and during ground contact (peak flexion), whilst minimal changes occurred distally at the ankle. In contrast, Phan and colleagues[15] reported reduced knee flexion at midstance and distal changes such as increased ankle plantarflexion at initial contact and reduced peak ankle dorsiflexion during ground contact when instructing runners to "make a quieter sound when you land" compared to habitual running. However, the use of barefoot, overground running by Phan and colleagues[15] could have mediated the change of distal kinematics and a stiffer lower limb during midstance due to heightened somatosensory feedback at the foot[31] and a stiffer running surface.

The larger knee flexion angles during impact with the external cue in the current study were brought about by the thigh being rotated further backwards (Table 2). This coupled with the greater peak knee flexion during midstance shows that runners were opting to reduce the sound of their running by adopting a crouching running style, similar to Groucho running[39]. This strategy can produce greater shock attenuation due to a more compliant lower limb, but at the expense of being exposed to higher tibial accelerations[39,40], which could place runners at risk of tibial stress fractures[41]. Clinicians implementing gait retraining should therefore be aware of these possible implications if runners adopt such a kinematic strategy when provided with a cue such as, or synonymous with, "run quietly". Given the knee flexion and potential stiffness adjustments made during the EF condition, an increase in $\dot{V}O_2$ would be expected[21,39]. However, and in support of our original hypothesis, this was not observed, $\dot{V}O_2$ actually remained unchanged. It is possible that these biomechanical alterations, while increasing the external mechanical work performed, led to improved movement efficiency as more work was performed without an increase in metabolic cost. Whilst movement efficiency is expected to be enhanced when using an EF cue[17], there is limited evidence to support this claim and it is difficult to quantify during running (see

Winter et al.[42] for a review). Further work is warranted to support the assertion that gait retraining using an instruction to direct attention to the effect of movement (EF) enhances movement efficiency by modifying mechanical work.

Contrary to our hypothesis, $\dot{V}O_2$ only increased significantly in the CLIN condition, but a large effect was observed for the IF condition due to consistent increases in $\dot{V}O_2$ across participants (Figure 4). The reductions in foot angle may have contributed to the increases in $\dot{V}O_2$, as a recent review identified that submaximal $\dot{V}O_2$ of rearfoot strikers may be detrimentally affected when foot angle is reduced[21]. However, this may only reflect an acute metabolic response as training interventions have shown unchanged or reduced submaximal $\dot{V}O_2$ over three and four weeks, respectively, with changes in foot kinematics such as reduced ankle dorsiflexion at initial contact[43] and subjective visual assessments of foot strike patterns[44]. These acute and chronic metabolic changes may reflect coordination adaptations in the motor system as it attempts to reorganise the degrees of freedom in order to meet and maintain the new requirements of the desired movement. Consequently, drawing upon both motor learning theory and economical running principles, individuals and their practitioners need to be aware that during gait retraining where a transition from a rearfoot strike to a flatter foot contact is being effected, an initial increase in the metabolic demand accompanied by a reduction in performance may be observed but that over time these will be negated as the motor system re-optimises.

It was notable that the CLIN condition produced a set of hybrid biomechanical responses, some of which were observed in the IF condition and others in the EF condition. Although these responses had large effect sizes, they were typically reduced in magnitude compared to the IF and EF conditions. The large increase in $\dot{V}O_2$ may reflect this hybrid running gait response, but it could also reflect conflicting motor task execution demands. Movements are planned according to their intended outcomes and adopting an external focus enhances the congruency between movement planning and outcome, improving the efficiency of motor programming[17]. When the fundamental premise of directing attention toward a clear movement effect, *either internal or external*, is confounded using internal and external focus cues together, as in the CLIN condition, the conflicting demands might explain the increased overall metabolic cost in terms of $\dot{V}O_2$, over and above the metabolic costs indexed by heart rate and central and peripheral effort. Given the hybrid responses and the clinical relevance of this cue, further work examining the acute delivery of task-relevant cues where an internal cue is presented initially to provide a kinaesthetic reference point and effect change, followed at some point in the future, but in the same session, by an external cue that promotes efficiency and fluidity is warranted.

The increase in central and peripheral perceptual effort, as well as heart rate, across all conditions partially supports our hypothesis with increases in these indices being observed in the IF condition as expected. However, contrary to our predictions, increases were also observed in the EF condition despite no change in $\dot{V}O_2$. This suggests that perceived effort was more closely aligned with heart rate responses than ventilatory responses. This supports a previous meta-analysis that identified a stronger relationship between heart rate and RPE, than $\dot{V}O_2$ and RPE for treadmill running[45]. In contrast to our findings, Hill and colleagues[23] observed no changes in RPE between an EF (a video) or movement-related IF ("concentrate on the movement of your legs") cue compared to a control run. The former of which is interesting considering a significant decrease in $\dot{V}O_2$ from the control run was reported in that condition. Unsurprisingly, considering the context of the cue, a difference was noted compared to the control and EF (but not the other IF) for the internal cue directed towards bodily sensations ("concentrate on your internal bodily signals and perceived exertion"). The RPE responses in the current study may, in part, reflect a sensed effort of producing biomechanical changes. Whilst RPE does not necessarily reflect objective, quantifiable mechanical changes[46], the cognitive demand of altering how your body moves ("run with a flat foot"/ "run quietly") is likely to be higher than focusing on what your body is doing when it moves ("concentrate on the movement of your legs"). This conceivably explains the differences between our findings and Hill et al.[23] and demonstrates that adopting the types of cues used in this study, have the potential to disrupt the coordination of movement and the resultant affect during running gait retraining. However, further interdisplinary work is necessary to provide a more detailed explanation for these coordination responses and to ascertain the source/s responsible for the reported perceptual changes.

In contrast to our expectation, shorter stride lengths and higher stride frequencies were found across all experimental conditions, with such alterations often linked to physiological and perceptual effort changes. However, the observed changes were marginal compared to previous experimental manipulations (3.6 vs. 7 – 20% respectively) and higher central RPE and heart rate have only been found when the stride length is 10% longer or 20% shorter than the preferred stride length[47,48]. Furthermore, the relative magnitude of the stride length shortening observed in the current study is similar to the optimal stride length range limit [preferred stride length minus 3%[21]]. Therefore, it is unlikely that these biomechanical alterations were directly related to increases in RPE and heart rate, suggesting it may be the disruption to task automaticity and/or additional cognitive demands of interpreting and implementing gait changes that affected RPE and heart rate.

The study was conducted on healthy runners who displayed a rearfoot strike pattern. Therefore, a limitation of the study is that it is not known whether injured runners would respond in a similar manner. However, IF verbal cues have been used to successfully reduce injury symptoms and change lower limb kinematics previously[2], but a comparison of motor learning strategies in symptomatic runners is warranted. The protocol employed considered only one gait retraining session without examining the within-session or post-session retention. Whilst, the acute nature of the current study may represent the access some clinicians have to patients within their practice, the findings cannot be generalised to predicting which motor learning strategy is most effective for the retention of gait changes. The order of conditions was fixed for all participants rather than randomised, which could produce a fatigue-related order effect when comparing the control and experimental conditions. Whilst the increase in heart rate and perceived effort may support this argument, the biomechanical findings appear to contradict it. For example, longer stride lengths, longer ground contact times and lower stride frequencies would be expected with fatigue[49], with the opposite or no change observed in the current study. Interactions were also recorded for two of the kinematic variables. Taken together, this pattern of effects suggests that the experimental manipulation rather than fatigue was responsible for the observed changes in both kinematic and physiological indices.

In conclusion, contrary to our prediction, using an internally directed focus of attention cue was most effective in eliciting a flatter foot angle. Adopting an external focus of attention produced proximal kinematic changes similar to a crouching running gait, whilst using an IF followed by an EF cue produced a biomechanical response that was a hybrid of the singular verbal cues and resulted in an increased submaximal $\dot{V}O_2$. An increased submaximal $\dot{V}O_2$ was also observed in the IF condition but despite a large effect size, the increase was non-significant. No $\dot{V}O_2$differences were observed in the EF condition indicating that it mitigated the potential detrimental effects of the biomechanical responses. Despite these varying changes in $\dot{V}O_2$, the type of task-relevant verbal cue did not affect perceptual effort responses, with higher peripheral and central RPE observed during all running gait retraining conditions. Adopting an interdisciplinary approach provided unique insight into the provision of running gait retraining, yet further work is needed to understand the effect of focus of attention on mechanical work and to quantify if these changes enhance movement efficiency.

Perspectives

Specific instructions regarding movement requirements provide the most effective way to change running gait. Utilising cues that direct attention externally (e.g. reducing sound) may produce the desired outcome in some (e.g. flatter foot contact), however, this allows individuals to take a more flexible approach in how they biomechanically adapt to produce the outcome and in some cases this may lead to the adoption of a technique (e.g. crouched running) that has the potential to actually increase the risk of injury. Whilst in certain contexts (e.g. golf putting) achieving a successful outcome is more important then how it is achieved, for retraining running gait where the outcome is to alter mechanical loading to facilitate a reduction in injury symptoms, the *how* is crucial. Therefore, clinicians are advised to use task-relevant verbal cues that direct attention internally during the early, acute stages of running gait retraining to produce specific biomechanical changes.

It is also recommended that a single motor learning strategy is used in order to produce the largest biomechanical changes, as incorporating both an IF and EF statement (CLIN condition) led to biomechanical responses seen in the single cue conditions but at a reduced magnitude. Additionally, even though the EF condition did not effectively elicit the desired biomechanical response (i.e., a flatter foot), it did mitigate against a potential increase in $\dot{V}O_2$. Therefore, if an appropriate task-relevant EF verbal cue is devised that elicits the desired biomechanical responses, this could be an effective way to retrain running gait whilst minimising disruption to running performance. However, the increased perceptual effort needs to be taken into consideration and it is likely that individual-specific EF cues may be required when using such an approach, based on the varied responses shown in the current study.

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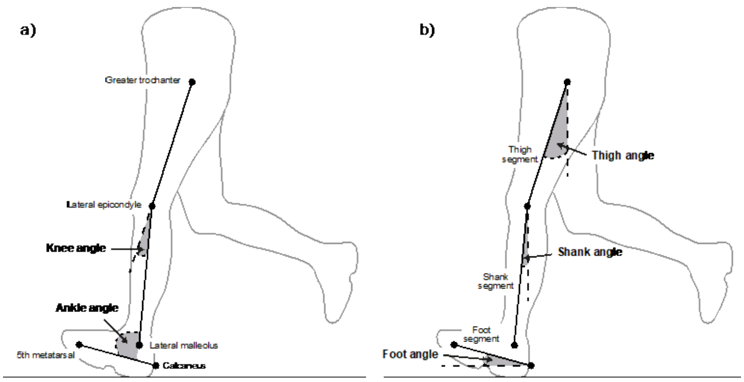

Figure 1. Schematic of a) Marker placements and joint angles (bold) and; b) Segments and segment angles (bold). Grey areas denote angles. Vertical and horizontal dotted lines in b) represent the vertical and horizontal axes from the laboratory coordinate system.

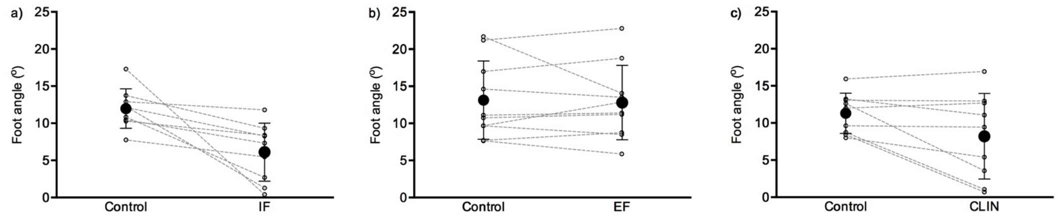

Figure 2. Mean ± SD (black circles with error bars) and participant-specific foot angle responses (white circles with dotted line) during a) internal focus of attention [IF]; b) external focus of attention [EF] and; c) clinical [CLIN] conditions compared to the respective control conditions.

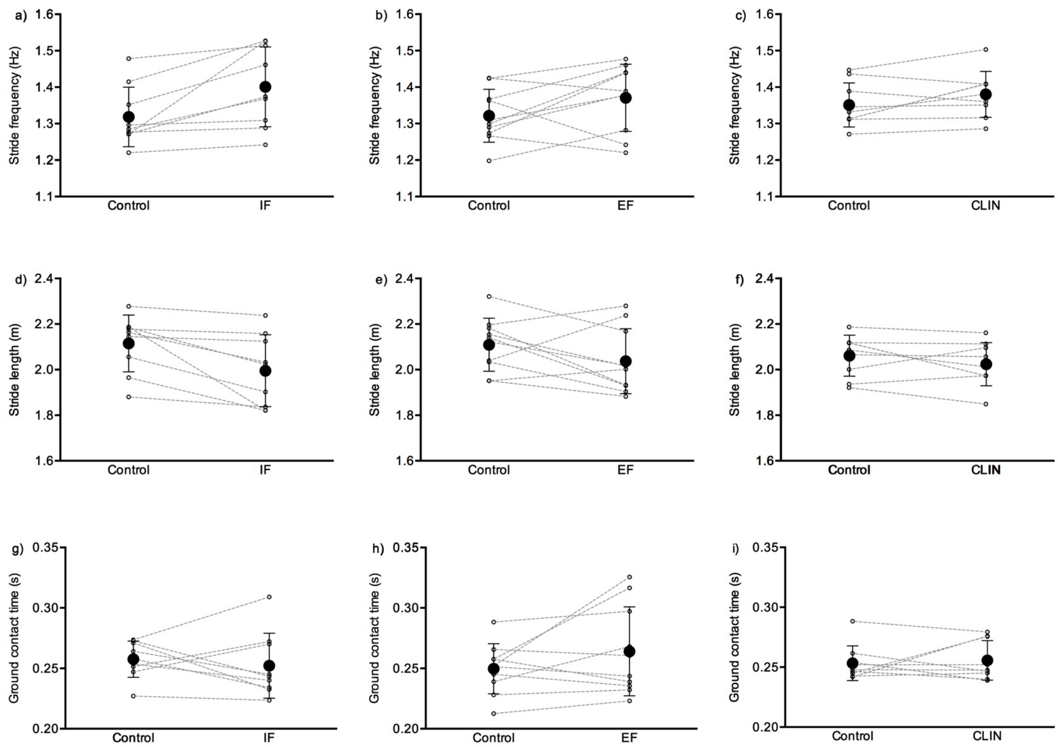

Figure 3. Mean ± SD (black circles with error bars) and participant-specific stride frequency, stride length and ground contact time responses (white circles with dotted line) during: internal focus of attention ([IF]; a, d and g respectively); external focus of attention ([EF]; b, e, and h respectively) and; clinical ([CLIN]; c, f and i respectively) conditions compared to the respective control conditions.

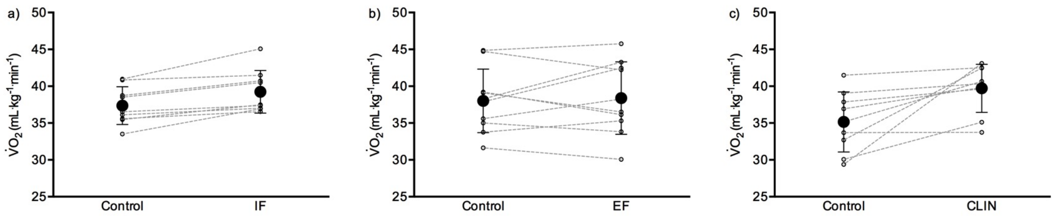

Figure 4. Mean ± SD (black circles with error bars) and participant-specific $\dot{V}O_2$ responses (white circles with dotted line) during a) internal focus of attention [IF]; b) external focus of attention [EF] and; c) clinical [CLIN] conditions compared to the respective control conditions.

Table 1. Mean (SDs) participant age, mass, and height for each group

Group	Age (years)	Mass (kg)	Height (m)
IF **(n = 9)**	24.9 (3.1)	78.8 (14.0)	1.81 (0.08)
EF **(n = 10)**	24.7 (3.3)	77.7 (18.0)	1.76 (0.13)
CLIN **(n = 9)**	23.6 (1.5)	79.0 (7.5)	1.78 (0.07)

n = group sample size. IF = internal focus of attention. EF = external focus of attention. CLIN = clinical focus of attention (IF followed by EF). No significant differences were found between groups.

Table 2. Means (SDs) of the biomechanical measures for each group per condition

Variable	**Condition**	**IF**	**EF**	**CLIN**
Foot angle at initial contact (°)	Control	12.0 (2.7)	13.1 (5.3)	11.3 (2.7)
	Experimental	6.1 (3.9)	12.8 (5.0)	8.3 (5.9)
Shank angle at initial contact (°)	Control	4.7 (2.9)	4.6 (3.0)	4.2 (4.2)
	Experimental	4.7 (3.3)	3.1 (2.9)	3.4 (4.3)
Thigh angle at initial contact (°)	Control	19.0 (3.6)	20.5 (3.3)	18.9 (3.7)
	Experimental	19.8 (3.1)	24.2 (5.9)	21.8 (4.5)
Ankle angle at initial contact (°)	Control	16.6 (3.8)	17.7 (5.8)	15.5 (6.2)
	Experimental	10.6 (7.0)	15.9 (4.6)	11.7 (9.2)
Peak dorsiflexion (°)	Control	25.6 (2.8)	24.5 (3.4)	22.6 (2.2)
	Experimental	24.9 (2.9)	24.6 (3.0)	25.1 (3.1)
Knee angle at initial contact (°)	Control	15.0 (5.0)	15.9 (5.0)	14.7 (3.4)
	Experimental	15.1 (4.7)	21.1 (5.0)	18.3 (3.5)
Peak knee flexion (°)	Control	44.1 (4.3)	41.5 (3.0)	41.7 (5.9)
	Experimental	42.9 (5.9)	45.7 (5.0)	44.6 (5.9)

IF = internal focus of attention. EF = external focus of attention. CLIN = clinical focus of attention (IF followed by EF).

Table 3. Means (SDs) of the physiological and perceptual measures for each group per condition

Variable	Condition	IF	EF	CLIN
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	Control	37.36 (2.55)	38.01 (4.32)	35.15 (4.08)
	Experimental	39.23 (2.89)	38.38 (4.91)	39.71 (3.26)
Heart rate (beats·min^{-1})	Control	141.9 (14.9)	151.4 (14.7)	153.5 (11.7)
	Experimental	149.6 (16.9)	160.9 (14.7)	167.3 (15.3)
Central RPE	Control	10.3 (1.9)	11.2 (2.3)	10.6 (1.8)
	Experimental	11.4 (2.2)	12.2 (2.0)	11.8 (2.3)
Peripheral RPE	Control	9.2 (1.9)	9.0 (2.1)	9.6 (2.0)
	Experimental	10.7 (2.3)	11.2 (2.5)	13.1 (2.5)

IF = internal focus of attention. EF = external focus of attention. CLIN = clinical focus of attention (IF followed by EF). $\dot{V}O_2$ = oxygen consumption. RPE = ratings of perceived exertion.

Table 4. Summary of two-way ANOVA (2x3; Condition x Group) results for each dependent variable

Measure	Effect	*df*	F-value	η_p^2
Foot angle at initial contact (°)	Interaction	**2,25**	4.18	.251*
	Condition	**1,25**	15.11	.377***
	Group	**2,25**	2.66	.176
Shank angle at initial contact (°)	Interaction	**2,24**	2.20	.155
	Condition	**1,24**	6.27	.207*
	Group	**2,24**	0.19	.016
Thigh angle at initial contact (°)	Interaction	**2,23**	2.31	.167
	Condition	**1,23**	19.46	.458***
	Group	**2,23**	1.22	.096
Knee angle at initial contact (°)	Interaction	**2,23**	3.58	.238*
	Condition	**1,23**	28.63	.555***
	Group	**2,23**	1.56	.120
Peak knee flexion (°)	Interaction	**2,22**	4.94	.310*
	Condition	**1,22**	9.06	.292
	Group	**2,22**	0.02	.002
Ankle angle at initial contact (°)	Interaction	**2,24**	1.54	.114
	Condition	**1,24**	15.80	.397***
	Group	**2,24**	0.94	.073
Peak dorsiflexion (°)	Interaction	**2,22**	2.23	.168
	Condition	**1,22**	0.78	.034
	Group	**2,22**	0.66	.056
Stride length (m)	Interaction	**2,25**	1.18	.086
	Condition	**1,25**	12.65	.336**
	Group	**2,25**	0.19	.015
Stride frequency (Hz)	Interaction	**2,25**	1.29	.094
	Condition	**1,25**	13.40	.349***
	Group	**2,25**	0.16	.012
Ground contact time (s)	Interaction	**2,25**	1.45	.104
	Condition	**1,25**	0.61	.024
	Group	**2,25**	0.04	.003
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	Interaction	**2,25**	4.08	.246*
	Condition	**1,25**	13.86	357***
	Group	**2,25**	0.17	.014
Heart rate (beats·min^{-1})	Interaction	**2,25**	1.16	.085
	Condition	**1,25**	39.49	.612***
	Group	**2,25**	2.32	.157
Central RPE	Interaction	**2,25**	0.16	.012
	Condition	**1,25**	19.62	.440**
	Group	**2,25**	0.47	.037
Peripheral RPE	Interaction	**2,25**	2.69	.177
	Condition	**1,25**	41.88	.626***
	Group	**2,25**	1.33	.096

$\dot{V}O_2$= oxygen consumption. RPE = ratings of perceived exertion. *$p \leq 0.05$. **$p \leq 0.01$. ***$p \leq 0.001$.