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Enhanced jump performance when providing augmented feedback compared to an external or internal focus of attention

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Abstract
Factors such as an external focus of attention (EF) and augmented feedback (AF) have been shown to improve performance. However, the efficacy of providing AF to enhance motor performance has never been compared with the effects of an EF or an internal focus of attention (IF). Therefore, the aim of the present study was to identify which of the three conditions (AF, EF or IF) leads to the highest performance in a countermovement jump (CMJ). Nineteen volunteers performed 12 series of 8 maximum CMJs. Changes in jump height between conditions and within the series were analysed. Jump heights differed between conditions ($P < 0.001$), resulting in best performance with AF (32.04 ± 7.11 cm), followed by EF (31.21 ± 6.67 cm) and IF (30.77 ± 6.87 cm). Significantly different ($P < 0.001$) within-series effects of higher jump heights at the end of the series in AF (+1.60%) and lower jump heights at the end of the series in EF (−1.79%) and IF (−1.68%) were observed. Muscle activity did not differ between conditions. The differences between conditions and within the series provide evidence that AF leads to higher performance and better progression within one series than EF and IF. Consequently, AF seems to outperform EF and IF when maximising jump height.

Keywords: *jump height, countermovement jump, muscle activity, ground reaction force*

Introduction

For both elite sports and rehabilitation, it is essential to use training regimens that lead to maximum adaptations. Thus, not only the timing of training schedules must be organised optimally, but also the content of each training session. In this respect, recent studies have highlighted that both adequate instructions and augmented feedback (AF) can positively affect motor performance in cross-sectional as well as learning studies. For example, in her review article, Wulf (2013) comes to the conclusion that using an external focus of attention (EF) is beneficial compared to using an internal focus of attention (IF) or to a condition without any instruction. Generally, an EF means that participants direct their attention on the effects of their movement on the environment, whereas an IF means that participants should focus their attention on body parts that are primarily involved in the movement. With respect to jumping movements, enhanced jump performance for maximum countermovement jumps (CMJs) (Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010) as well as standing long jumps (Porter, Anton, Wikoff, & Ostrowski, 2013; Porter, Anton, & Wu, 2012; Porter, Ostrowski, Nolan, & Wu, 2010; Wu, Porter, & Brown, 2012) was reported when participants used an EF. Interestingly, it was also shown that despite the enhanced jump performance, muscular activity is generally reduced in CMJs when using an EF compared to an IF (Wulf et al., 2010).

A second approach to enhance motor performance directly and in the long run is to use AF that is provided by an external source such as coaches or computer devices (for review, see Lauber & Keller, 2014). In this regard, it has been shown that providing online force/torque feedback (Baltzopoulos, Williams, & Brodie, 1991; Figoni & Morris, 1984; Hopper, Berg, Andersen, & Madan, 2003) can immediately enhance motor performance in maximum force tasks. Similarly, feedback that is provided after the end of the movement can also influence motor performance in the long run (Moran, Murphy, & Marshall, 2012). Similar observations were recently made with respect to drop jump performance (Keller, Lauber, Gehring, Leukel, &

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Taube, 2014). The authors found immediate effects of AF on jump height before and after a training period. Furthermore, they also showed that the higher the frequency at which AF was provided, the better the training adaptation in the long term. However, the authors could not draw a final conclusion to explain why the jump height was enhanced. It was argued that the enhanced performance in response to AF might be the result of enhanced motivation or a shift in the focus of attention. As mentioned above, focussing on the outcome of a task rather than focussing on body parts or kinematics can enhance performance and learning (for review, see Wulf, 2013). In this respect, Moran et al. (2012) speculated that providing AF as knowledge of result (e.g. providing the jump height) may cause a shift in the focus of attention towards an EF, which in turn may result in enhanced performance values. Consequently, one would assume similar observations when participants are actually asked to apply an EF or when receiving AF. This question has, however, not been addressed so far. Thus, the aim of the present study was to investigate the effects of EF, IF and AF on jump height in order to clarify the most beneficial approach for increasing performance over the short term. We hypothesised that providing AF or using an EF leads to higher jump heights than adopting an IF. For the comparison of AF with an EF/IF, the outcome was unpredictable as this is the very first study investigating this issue. As a second main outcome, electromyography (EMG) activity was analysed for each condition. Previous studies have shown that – despite enhanced motor performance when using an EF – muscular activity was lower with EF than with IF (Marchant, Greig, & Scott, 2009; Vance, Wulf, Tollner, McNevin, & Mercer, 2004; Wulf et al., 2010). It was therefore hypothesised that a higher level of muscular activity would be found in the IF condition compared to the EF condition. Again, due to the novelty of the present approach, no hypothesis could be made for the comparison of the AF and EF/IF conditions.

Methods

Participants

Nineteen physically active university students (27.5 ± 4.2 years, 1.75 ± 0.08 m, 69.1 ± 11.7 kg; 11 male and 8 female) with no history of neurological and/or orthopaedic injuries participated in this study. All participants gave written informed consent after reading a participant information sheet explaining the applied methods and devices. The experimental procedure was in line with the latest declaration of Helsinki and was approved by the ethics commission of the Canton of Fribourg. Inclusion criteria for all participants were: (i) a minimum of two training sessions per week in sports that include reactive movements (running, hockey, basketball, soccer) and (ii) unawareness about the expected effects of AF and an altered focus of attention on motor performance. All participants were told that the aim of this study was to assess the most efficient instruction as all these instructions would be commonly used in the training of elite athletes without providing any knowledge about the effects of AF, EF and IF on jump height.

Experimental protocol

After a 10-min warm-up (jogging and hopping), participants were familiarised with the jumping procedure by watching a video of a well-trained athlete performing a CMJ in exactly the same environmental setting. Participants were then instructed to jump as high as possible with maximum effort. No advice was given with respect to joint angles and overall movement duration. Participants were asked to place both feet symmetrically on the force plate and to perform all jumps with the hands at the hip. Additionally, participants were asked to keep the jumping procedure similar throughout all jumps with regard to starting position on the platform and head position. For customisation, participants performed ten submaximal and ten maximum CMJs that were not part of the analysis.

Recordings started with five maximum CMJs without instructions regarding the focus of attention and without AF. Another five maximum jumps were measured in exactly the same way at the very end of the experiment to account for potential effects of fatigue. For the main protocol, participants were asked to perform 12 series consisting of eight maximum jumps per series. Participants were asked to rest for 10 s between two consecutive jumps and for 4 min between series. Within each series, instructions were the same but varied between the individual series. Thus, all participants performed four series using an EF, four series using an IF and four series with an AF. The order in which the participants performed the first three series of jumps (EF, IF and AF) was randomised between participants but was then kept identical for the rest of the measurements (e.g. the first series AF, the second series IF, the third series EF, the fourth series AF).

The instructions regarding the focus of attention given to the participants were based on instructions that have been used previously for standing long jumps (Porter et al., 2013, 2012, 2010) but were slightly adapted to the specifications of CMJs. All instructions were given before the start of a series and repeated before every single jump by reading the predefined instruction.

External focus of attention. For the EF condition, a tennis ball was attached to the ceiling over the force plate. The height of the tennis ball was individually adjusted for each participant depending on the highest jump height achieved during the familiarisation trials. This means that the ball was approximately 5 cm above the apex the head reached during familiarisation trials. The rationale for the additional 5 cm was to exclude any kind of additional feedback like touching the ball. Participants could not see the ball during jumping as it was mounted directly over their head, and participants were instructed to look straight ahead. Thus, participants could not estimate their jump height due to enhanced visual or sensory feedback. The following instruction was given: "When you are attempting to jump as high as possible, I want you to focus your attention on jumping as close to the ball as you possibly can." Thus, we chose an instruction that asked participants to direct attention externally to a target that is far from the starting point. It was recently shown that focussing externally enhances performance more significantly if the distance of the EF from the body is increased (Porter et al., 2013, 2012).

Internal focus of attention. For the IF condition, the following instruction was used: "When you are attempting to jump as high as possible, I want you to focus your attention on extending your legs as rapidly as possible."

Augmented feedback. In the AF condition, AF about the jump height was visually displayed directly after landing (22-inch screen and font size 72). The following instruction was given: "When you are attempting to jump as high as possible, I want you to maximise the number on the screen indicating your jump height."

Apparatus

Electromyography. Muscular activity was obtained from M. soleus (SOL), M. gastrocnemius medialis (GM), M. tibialis anterior (TA) and M. vastus medialis (VM) of the right leg with a custom-built EMG device (EISA, University of Freiburg, Germany). EMG preparation and electrode placement (Blue Sensor P, Ambu A/S®, Ballerup, Denmark) were performed according to the SENIAM guidelines (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The reference electrode was placed on the tibial plateau. Interelectrode impedance was kept below 5 kΩ. All electrodes were checked for movement artefacts by actively and passively shaking the right leg. EMG data were amplified (1 kHz), band-pass filtered (10–1000 Hz) and sampled at 4 kHz. Custom-built software (LabView®-based National Instruments®, Austin, Texas, USA) was used for recordings and offline analysis of all data.

Kinetic data. A 508 × 464 mm force plate (OR6-7 force platform; Advanced Mechanical Technology Inc., Watertown, MA, USA) was used for the analysis of jump height and vertical ground reaction forces (vGRFs). The kinetic data were sampled at 4 kHz.

Feedback device. A light barrier (MLGE2, SICK AG, Waldkirch, Germany) was used to assess the rebound height directly. Custom-built software (LabView®-based National Instruments®, Austin, Texas, USA) calculated the achieved jump height according to the following formula: $jump\ height = \frac{g*t^2}{8}$, where t is the duration of the flight phase and g represents the acceleration of gravity.

Data analysis and statistics

Kinetic data. Data from the vGRF were used to analyse the jump height. Data points from vertical GRF with values less than 5 N were considered to represent the flight phase. The duration of the flight phase was used to calculate the jump height using the formula mentioned above. Additionally, different parameters of the vGRFs were analysed (see Figure 1) in order to compare conditions (EF, IF and AF). A recent study (Wu et al., 2012) evaluated the maximum peak of the vGRF but was not able to explain differences in jump performance between conditions (IF vs EF) using this parameter. Therefore, the present study assessed differences in the vGRFs more detailed in order to evaluate whether the different instructions affected the movement patterns differently. The maximum peak (F_{max}) in vGRF was assessed as well as the time point when F_{max} occurred prior to take-off ($t_{F\max}$). Based on these data, the time-normalised force production was calculated by dividing F_{max} by $t_{F\max}$ (time-normalised force production$_{max}$ = $F_{max}/|t_{F\max}|$). Similarly, the minimum force peak (F_{min}) and its corresponding time point prior to take-off ($t_{F\min}$) were analysed.

Within-series effects. In order to evaluate potential differences in jump height within a series, we compared the jump height of the first two jumps with the height of the last two (seventh and eighth) jumps of the same series. The mean of the last two jumps was expressed as a percentage of the mean of first two jumps in order to evaluate the within-series alterations. We conducted this comparison for all 12 series so that we had four comparisons per condition. The overall within-series effect was calculated using mean values for every condition.

Electromyographic data. EMG activity was analysed between the onset of muscle activity and the take-off. The root mean square (RMS) value of EMG data was calculated backwards in fixed time intervals of 50 ms starting from take-off (time at take-off was defined as

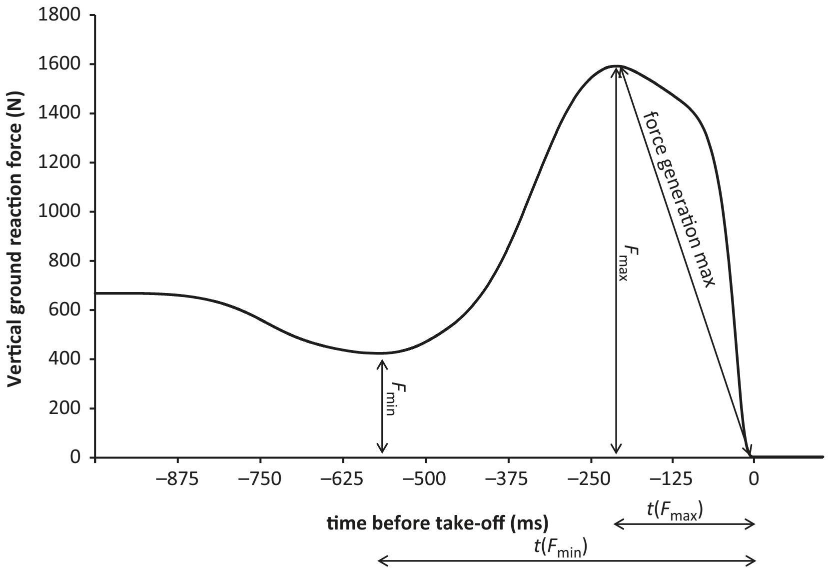

Figure 1. An exemplary vertical ground reaction force of one countermovement jump prior to take-off. Based on each individual trial, the displayed parameters were analysed for each condition (internal focus of attention vs external focus of attention vs augmented feedback). The amplitudes and temporal occurrences of the maximum (F_{max} and t_{Fmax}) and the minimum peaks (F_{min} and t_{Fmin}) of the vertical ground reaction force were analysed. The time-normalised force production was calculated by dividing F_{max} by t_{Fmax}.

0 ms) until the onset of muscular activation. The onset of muscle activity was defined as the point at which the EMG level reached twice the activity measured during bipedal upright standing. Subsequently, muscular activity was assessed by calculating the RMS from the onset of muscle activity until take-off.

Statistics. All data were tested for normal distribution using the Shapiro–Wilk test, and analyses of variance (ANOVAs) were only performed if normality as well as sphericity (Mauchly's sphericity test) was given. Differences in jump height and within-series effects between the conditions were analysed using an ANOVA. The same statistical test was used for the evaluation of differences in the vGRF (F_{max}, t_{Fmax}, F_{min}, t_{Fmin} and time-normalised force production$_{max}$). Potential differences in EMG activity and onset of muscle activity were tested using a one-way ANOVA for each muscle. In case of significant *F*-values ($P < 0.05$), Bonferroni-corrected Student's *t*-tests were calculated to assess differences between conditions. Furthermore, effect sizes are presented in the partial eta square values (η^2_p: small effect: 0.02; medium effect: 0.13; large effect: 0.26). SPSS 19.0 software was used for all statistical analyses. Data are presented as group mean values ± standard deviation, if not otherwise indicated.

Results

Kinetic data: jump height

The results show that jump heights differed significantly between conditions ($F_{2,36} = 32.66$; $P < 0.001$; $\eta^2_p = 0.65$) with the highest jump heights observed in the AF condition, followed by the EF and IF conditions (see Figure 2; IF vs EF: $P < 0.05$; IF vs AF: $P < 0.001$; EF vs AF: $P < 0.001$). The performance in the last five jumps without instructions regarding the focus of attention and without AF was significantly higher compared to the initial five jumps (first five jumps: 29.0 cm; last five jumps: 31.0 cm; $P < 0.01$), indicating that fatigue did not play a significant role.

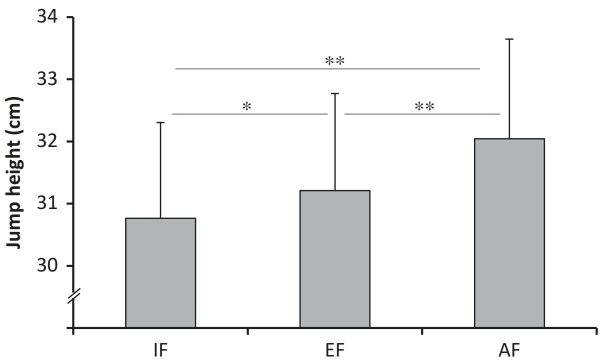

Figure 2. The highest jump height observed when the jump height was visually displayed (AF: augmented feedback), followed by the external focus of attention condition (EF) and the internal focus of attention condition (IF). Data are shown as mean ± standard error.

Kinetic data: ground reaction forces

Analyses revealed significant differences in F_{min} between conditions ($F_{2,36} = 5.46$; $P < 0.001$; $\eta^2_p = 0.23$) with the lowest forces observed in the IF

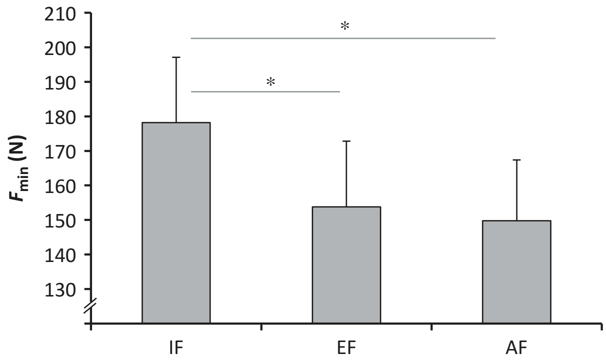

Figure 3. The minimum force of the vertical ground reaction force differed significantly between conditions with the highest value observed in the internal focus of attention (IF) condition in comparison with the external focus of attention (EF) and augmented feedback (AF) conditions. Data are shown as mean ± standard error.

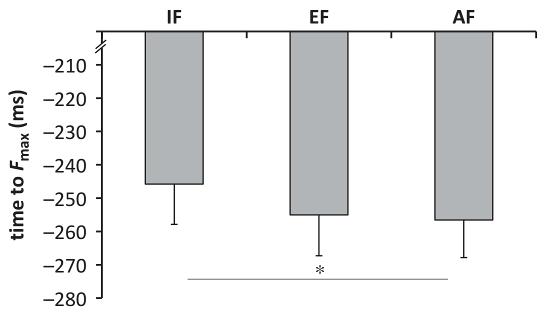

Figure 4. The time point when the maximum peak in vertical ground reaction force (F_{max}) occurred prior to take-off (being 0 ms in this case) differed significantly between conditions. In the internal focus of attention (IF) condition, the force peak of F_{max} was closest to take-off in comparison with the external focus of attention (EF) and augmented feedback (AF) conditions. Data are shown as mean ± standard error.

condition (see Figure 3). However, we did not find any differences between conditions for the time point when F_{min} occurred before take-off ($t_{F\min}$: $F_{2,36}$ = 1.67; P = 0.20; η^2_p = 0.09) (see Table I). The maximum force peak in vertical direction F_{max} also did not differ between conditions (F_{max}: $F_{2,36}$ = 1.23; P = 0.31; η^2_p = 0.06) (please find the absolute values in Table I). However, independently of the unaffected size of F_{max}, we observed significant differences between conditions for the time point when F_{max} occurred prior to take-off ($t_{F\max}$: $F_{2,36}$ = 5.95; $P < 0.01$; η^2_p = 0.25) (see Figure 4). In the IF condition, $t_{F\max}$ was smallest and therefore closest to take-off compared to the AF and EF conditions. Furthermore, the time-normalised force production$_{max}$ differed significantly between conditions ($F_{2,36}$ = 3.34; $P < 0.05$; η^2_p = 0.16) with the highest value observed in the IF condition (see Figure 5).

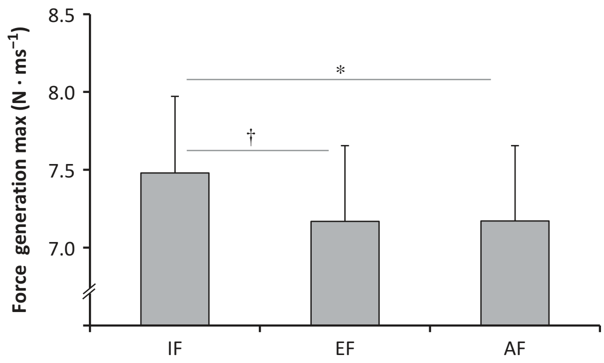

Figure 5. The maximal force production is shown for all three conditions. The highest force production was found for the internal focus of attention (IF) condition, and it was significantly larger than it was for the augmented feedback (AF) condition and showed a trend to be higher than it was for the external focus of attention (EF) condition. Data are shown as mean ± standard error.

Electromyographic data

The results of the present study showed no significant differences in muscular activity (see Table I). The onsets of muscle activity did not differ significantly between conditions (TA: $F_{2,36}$ = 1.25, P = 0.30, η^2_p = 0.07; SOL: $F_{2,36}$ = 1.51, P = 0.23,

Table I. Nonsignificant differences between IF (internal focus of attention), EF (external focus of attention) and AF (augmented feedback) conditions found for the parameters. Kinetic data (peak force and the time point of the minimal force peak) as well as muscular activity of different muscles (TA: M. tibialis anterior, SOL: M. soleus, GM: M. gastrocnemius medialis, VM: M. vastus medialis) are displayed.

	IF	EF	AF
Peak forces: F_{max} (N)	1961.33 ± 633.95	1947.06 ± 641.71	1970.90 ± 639.22
Time point of minimal force: $t_{F\min}$ (ms)	−518.42 ± 98.45	−528.95 ± 82.61	−524.21 ± 92.09
Onset of muscle activity (TA) (ms)	718.42 ± 186.50	731.58 ± 172.57	728.95 ± 178.20
Onset of muscle activity (SOL) (ms)	386.84 ± 59.73	402.63 ± 69.67	392.11 ± 71.22
Onset of muscle activity (GM) (ms)	294.74 ± 62.13	313.16 ± 59.73	297.37 ± 65.56
Onset of muscle activity (VM) (ms)	454.54 ± 68.76	459.09 ± 76.87	472.72 ± 41.01
Activity after onset of muscle activity (TA) (mV)	0.11 ± 0.06	0.11 ± 0.06	0.11 ± 0.06
Activity after onset of muscle activity (SOL) (mV)	0.21 ± 0.21	0.22 ± 0.21	0.22 ± 0.21
Activity after onset of muscle activity (GM) (mV)	0.23 ± 0.06	0.24 ± 0.06	0.24 ± 0.06
Activity after onset of muscle activity (VM) (mV)	0.14 ± 0.11	0.15 ± 0.11	0.15 ± 0.11

Note: Data are shown as mean ± standard deviation.

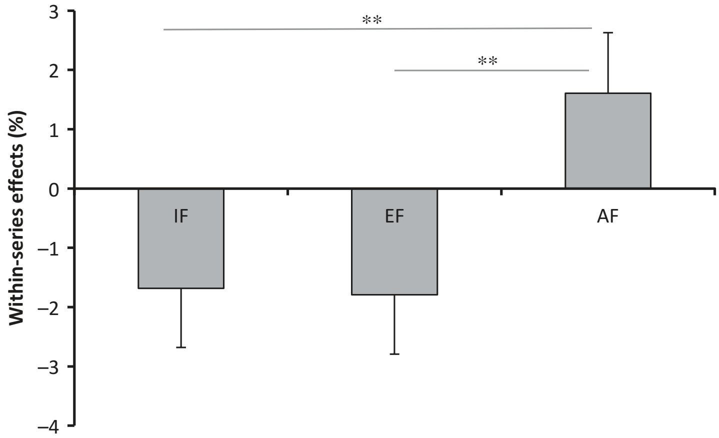

Figure 6. The within-session effects were evaluated by expressing the last two jumps of one series as a percentage of the first two jumps of the same series. Participants jumped higher at the end of the series with augmented feedback (AF), whereas a diminished jump height at the end of the series was observed for the internal focus of attention (IF) and external focus of attention (EF) conditions.

$\eta^2_p = 0.08$; GM: $F_{2,36} = 1.28$, $P = 0.29$, $\eta^2_p = 0.07$; and VM: $F_{2,20} = 0.66$, $P = 0.53$, $\eta^2_p = 0.06$), and we did not find any differences in muscular activity between conditions (TA: $F_{2,36} = 1.13$, $P = 0.33$, $\eta^2_p = 0.06$; SOL: $F_{2,36} = 1.97$, $P = 0.155$, $\eta^2_p = 0.10$; GM: $F_{2,36} = 1.46$, $P = 0.25$, $\eta^2_p = 0.08$; VM: $F_{2,36} = 1.15$, $P = 0.33$, $\eta^2_p = 0.06$).

Within-series alterations

The within-series alterations showed significant differences between conditions ($F_{2,36} = 20.88$; $P < 0.001$; $\eta^2_p = 0.54$) with higher jump heights at the end of a series observed in the AF condition and reduced jump heights at the end of a series observed in the IF and EF conditions (see Figure 6). It is further remarkable that the first jump was already significantly different between conditions ($F_{2,36} = 13.03$; $P < 0.001$; $\eta^2_p = 0.42$) with the highest jump height observed in the AF condition (32.03 ± 7.15 cm), followed by the EF (31.66 ± 6.93 cm) and the IF conditions (31.14 ± 7.10 cm) (IF vs EF: $P < 0.01$; IF vs AF: $P < 0.001$; AF vs EF: $P = 0.06$).

Discussion

The results of the present study show that the use of AF results in a better CMJ performance compared to the use of an EF or IF. The condition-related differences in vGRFs indicate different jumping strategies between conditions.

Internal versus external focus of attention

So far, many studies have focussed on the effect of using an altered focus of attention (EF vs IF) on motor task performance. The majority of these findings suggest that an EF is superior to an IF in cross-sectional (short-term) and longitudinal (long-term) training studies (for review, see Wulf, 2013). Our results show better performance with an EF than with an IF and are therefore well in line with previous studies. However, in the present study, we found consistent but with respect to the magnitude only small differences (≈ 0.5 cm) in vertical jump height between the IF and EF conditions, whereas previous studies reported differences of up to 3.3 cm for vertical jumps (Wulf & Dufek, 2009; Wulf et al., 2010) and 14 cm (Wu et al., 2012) and 10 cm (Porter et al., 2010) for standing long jumps. This discrepancy may be related to the fact that in some of the previous studies, participants were asked to reach for clearly visible horizontal rungs during the jump, enabling them to judge their own performance accurately (Wulf & Dufek, 2009; Wulf et al., 2010). Although this is clearly an EF, it nevertheless provides participants with additional information (AF) about their jump height what should be prevented because additional visual feedback could mask the effects of different focus instructions (recommendations given by Wulf, 2013). In contrast to previous studies, the participants in the current study did not receive any additional feedback in any of the two conditions (IF and EF) and were therefore not able to judge their jump performance accurately. Furthermore, it has to be highlighted that some previous studies asked participants in the IF condition to focus on the fingers with which they wanted to touch the rungs, whereas participants had to focus in the EF condition on the rungs they aimed to touch (Wulf & Dufek, 2009; Wulf et al., 2010). As the finger is obviously involved only at the very end of the jump (when touching the rungs), perhaps focussing on a finger shifted attention towards a limb that is nonrelevant for jumping performance, a concern which has already been raised before (Peh, Chow, & Davids, 2011). Contrarily, focussing on a high rung in the EF condition was a task-relevant focus. Thus, the large difference between EF and IF conditions in these studies might be explained by rather ambiguous chosen instruction in the IF condition that was not task relevant and therefore not suited to fostering maximal jump performance. Additionally, it has to be highlighted that a previous review (Kakebeeke, Knols, & De Bruin, 2013) and a theoretical paper (Peh et al., 2011) have criticised the generalisability of the focus of attention theory in the sense that an EF is not necessarily superior to an IF. Finally, there is recent empirical evidence showing that adopting an IF does not automatically lead to a reduced performance (Schücker, Knopf, Strauss, & Hagemann, 2014).

Another point that might be important for evaluating the magnitude of adaptation with respect to the focus of attention is the testing of one and the same population in the different conditions (IF and EF). Porter et al. (2010) reported large differences (~10 cm) between separate EF (n = 60) and IF groups (n = 60) when testing standing long jumps. Unfortunately, the study can therefore not clarify whether the findings are due to the focus of attention or to random differences between these two groups.

In order to get a better understanding about the differences in performance caused by changing the focus of attention, we analysed the ground reaction forces in detail. Based on the vGRF, it seems that movement patterns were influenced by the focus of attention as shown by differences in F_{min}, t_{Fmax} and the time-normalised force production$_{max}$ (see Figures 3–5). Participants showed the highest time-normalised force production and the smallest t_{Fmax} value in the IF condition, indicating that the participants really put the instruction "extending your legs as rapidly as possible" into action. Furthermore, the instruction "extending your legs" may have prevented the normal countermovement so that participants showed less reduction in force (=higher F_{min}) in this phase of the movement. Therefore, it seems that the instruction "extending your legs as rapidly as possible" interfered with the flexion movement during the countermovement but not with the actual extension of the legs. If this assumption is supported by future studies, upcoming projects need to ensure that instructions used for IF conditions do not lead to such unwanted side effects.

Augmented feedback versus external focus of attention

The present data show for the first time that when task performance has to be maximised within training trials, provision of AF is superior to an EF and to an IF, as participants jumped highest with AF. Both AF and EF have previously been shown to enhance motor performance directly. Displaying the performance (AF) resulted, for example, in enhanced jump heights (Keller et al., 2014) or increased force levels (Figoni & Morris, 1984; Hopper et al., 2003). Similarly, using an EF was shown to enhance performance immediately in comparison with using an IF or to a control condition (for review, see Wulf, 2013). In a recent study, Moran et al. (2012) speculated that, amongst other mechanisms, the provision of AF may act very similarly to an EF by drawing the participant's attention to an external source (e.g. a number displayed on a computer screen). The findings of the present study, however, question this assumption as providing AF resulted in a significantly better performance than using an EF. Therefore, the effects of AF can hardly be explained by solely drawing attention to the effects of the movement (EF). More reasonably, one may argue in line with Keller et al. (2014) that providing AF could also have motivated participants to perform the jumps with higher intensity. This argument is in line with the energisation theory of Brehm and Self (1989), which states that task engagement rises in relation to task difficulty. Therefore, one may argue that the AF condition represents the most challenging condition, as it is the only condition that asks participants to enhance performance from trial to trial. This may also explain the within-series effects that are discussed in the following section.

Within-series effects

As shown in Figure 6, only the AF condition resulted in enhanced jump heights at the end of a series, whereas the IF and EF conditions resulted in diminished jump heights at the end of a series. Therefore, one might speculate that participants performed jumps with greater effort at the end of a series only in the presence of AF. It may therefore be argued that enhanced jump heights in the AF condition at the end of a series may be due to motivational factors. In a previous study, we already indicated that as soon as AF is provided, participants increase their jump performance instantly (Keller et al., 2014). The current findings support this as the first jump of the AF condition was already higher than the jumps in the IF and EF conditions. Furthermore, the provision of AF might have kept the participants alert and motivated (Schmidt & Lee, 2011) until the end of the series, whereas motivation and therefore performance might have declined in the other conditions, as no objective values were presented.

An alternative explanation for the enhanced jump height at the end of a series in the AF condition could be based on short-term adaptation within one series.

It is well accepted that AF has the potential to guide the learner towards an optimised movement technique (Salmoni, Schmidt, & Walter, 1984). Therefore, it could be that participants learnt within one series to improve their movement technique without consolidation for the subsequent series. Unfortunately, we cannot identify the exact mechanism(s). It can, however, be concluded that providing AF helps participants jump higher at the end of a series, whereas a diminished performance was observed at the end of a series in the IF and EF conditions.

Electromyographic data

There was no difference in the onset of muscular activity, and the time point of the minimal force of the ground reaction force ($t_{F\min}$) did not differ when comparing the three conditions (IF, EF and AF). This observation is well in line with a previous study showing no significant differences in onset times when comparing an IF and an EF (Wulf et al., 2010).

Furthermore, the current data did not demonstrate differences in muscular activity between the EF and IF conditions and do therefore not support the initial hypothesis. Although there is one study proposing generally lower EMG activity when using an EF compared to an IF in CMJs (Wulf et al., 2010), a more recent study indicates comparable activity in the prime movers but reduced activity in the antagonist muscle when performing an isometric force task (Lohse, Sherwood, & Healy, 2011). Although we measured activity in three shank muscles and the VM, we did not assess EMG of hamstring muscles. Furthermore, not all agonistic muscles were covered so that it remains elusive whether changes in muscular activity did not occur in muscles not recorded in the current study. We analysed cocontraction levels for the shank muscles (SOL vs TA and GM vs TA; data not shown) but could not find any differences. However, this analysis was not possible for the thigh muscles.

Limitations of the study

In summary, AF can be recommended for the promotion of performance in CMJs. We acknowledge, however, that this study has some limitations like we only measured muscular activity of the VM but not of other quadriceps or hamstring muscles. Thus, cocontraction levels or onsets of muscle activity could not be assessed for all prime movers. Furthermore, the cross-sectional design of the present study does not allow conclusions for long-term training outcomes. Nevertheless, the observed results are of high practical relevance as providing AF leads to the highest performance within one training session what in turn might also be most efficient in the long term.

Conclusion

The present data highlight that providing AF leads to enhanced performance than using an EF or IF. Thus, the increased performance in response to AF cannot simply be attributed to a shift of attention towards an external target. In our point of view, the most likely explanation for the present results is an increase in motivation due to the fact that the first jump of the AF condition was already higher than the jumps in the IF and EF conditions.

With respect to EF versus IF, future studies have to consider that the instructions can strongly influence performance outcomes. The data of the present study highlight that participants show the highest force production values but the lowest jump heights with an IF. Furthermore, participants displayed the lowest troughs in the ground reaction curves during the countermovement in the IF condition. Thus, participants using an IF effectively transformed the instruction "extending your legs" into action, but this may have affected overall coordination in a negative way. Consequently, not the IF itself but rather an inappropriate instruction might be responsible for the diminished performance compared to a condition using an EF.

References

Baltzopoulos, V., Williams, J. G., & Brodie, D. A. (1991). Sources of error in isokinetic dynamometry: Effects of visual feedback on maximum torque measurements. *The Journal of Orthopaedic and Sports Physical Therapy*, *13*, 138–142.

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual Review of Psychology*, *40*, 109–131.

Figoni, S. F., & Morris, A. F. (1984). Effects of knowledge of results on reciprocal, isokinetic strength and fatigue. *The Journal of Orthopaedic and Sports Physical Therapy*, *6*, 190–197.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *10*, 361–374.

Hopper, D. M., Berg, M. A. A., Andersen, H., & Madan, R. (2003). The influence of visual feedback on power during leg press on elite women field hockey players. *Physical Therapy in Sport*, *4*, 182–186.

Kakebeeke, T. H., Knols, R. H., & De Bruin, E. D. (2013). Should rehabilitation specialists use external focus instructions when motor learning is fostered? A systematic review. *Sports*, *1*, 37–54.

Keller, M., Lauber, B., Gehring, D., Leukel, C., & Taube, W. (2014). Jump performance and augmented feedback: Immediate benefits and long-term training effects. *Human Movement Science*, *36*, 177–189.

Lauber, B., & Keller, M. (2014). Improving motor performance: Selected aspects of augmented feedback in exercise and health. *European Journal of Sport Science*, *14*, 36–43.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2011). Neuromuscular effects of shifting the focus of attention in a simple force production task. *Journal of Motor Behavior*, *43*, 173–184.

Marchant, D. C., Greig, M., & Scott, C. (2009). Attentional focusing instructions influence force production and muscular

activity during isokinetic elbow flexions. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, *23*, 2358–2366.
Moran, K. A., Murphy, C., & Marshall, B. (2012). The need and benefit of augmented feedback on service speed in tennis. *Medicine and Science in Sports and Exercise*, *44*, 754–760.
Peh, S. Y., Chow, J. Y., & Davids, K. (2011). Focus of attention and its impact on movement behaviour. *Journal of Science and Medicine in Sport*, *14*, 70–78.
Porter, J. M., Anton, P. M., Wikoff, N., & Ostrowski, J. (2013). Instructing skilled athletes to focus their attention externally at greater distances enhances jumping performance. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, *27*, 2073–2078.
Porter, J. M., Anton, P. M., & Wu, W. F. (2012). Increasing the distance of an external focus of attention enhances standing long jump performance. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, *26*, 2389–2393.
Porter, J. M., Ostrowski, E. J., Nolan, R. P., & Wu, W. F. (2010). Standing long-jump performance is enhanced when using an external focus of attention. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, *24*, 1746–1750.
Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin*, *95*, 355–386.
Schmidt, R. A., & Lee, T. (2011). Augmented feedback. In R. A. Schmidt & T. Lee (Eds.), *Motor control and learning: A behavioral emphasis* (5th ed., pp. 393–427). Champaign, IL: Human Kinetics.
Schücker, L., Knopf, C., Strauss, B., & Hagemann, N. (2014). An internal focus of attention is not always as bad as its reputation: How specific aspects of internally focused attention do not hinder running efficiency. *Journal of Sport & Exercise Psychology*, *36*, 233–243.
Vance, J., Wulf, G., Tollner, T., McNevin, N., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior*, *36*, 450–459.
Wu, W. F., Porter, J. M., & Brown, L. E. (2012). Effect of attentional focus strategies on peak force and performance in the standing long jump. *Journal of Strength and Conditioning Research/National Strength & Conditioning Association*, *26*, 1226–1231.
Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology*, *6*, 77–104.
Wulf, G., & Dufek, J. S. (2009). Increased jump height with an external focus due to enhanced lower extremity joint kinetics. *Journal of Motor Behavior*, *41*, 401–409.
Wulf, G., Dufek, J. S., Lozano, L., & Pettigrew, C. (2010). Increased jump height and reduced EMG activity with an external focus. *Human Movement Science*, *29*, 440–448.