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Maximizing Performance: Augmented Feedback, Focus of Attention, and/or Reward?

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ABSTRACT

WÄLCHLI, M., J. RUFFIEUX, Y. BOURQUIN, M. KELLER, and W. TAUBE. Maximizing Performance: Augmented Feedback, Focus of Attention, and/or Reward? *Med. Sci. Sports Exerc.*, Vol. 48, No. 4, pp. 714–719, 2016. **Purpose**: Different approaches like providing augmented feedback (aF), applying an external focus of attention (EF), or rewarding participants with money (RE) have been shown to instantly enhance motor performance. So far, these approaches have been tested either in separate studies or directly against each other. However, there is no study that combined aF, EF, and/or RE to test whether this provokes additional benefits. The aim of the present study was therefore to identify the most powerful combination. **Methods**: Eighteen participants performed maximal countermovement jumps in six different conditions: neutral (NE), aF, RE, aF + EF, aF + RE, and aF + EF + RE. **Results**: Participants demonstrated the highest jump heights with aF + EF, followed by aF + EF + RE, aF + RE, aF, RE, and finally, NE. Activity of the M. rectus femoris differed significantly between conditions resulting in lower muscular activity in aF + EF and aF + EF + RE compared with NE. All other parameters, such as ground reaction forces and joint angles, were comparable across conditions. **Conclusions**: This is the first study showing superior performance when combining aF with EF. As reduced muscular activity was found only in conditions with EF, it is argued in line with the constrained action hypothesis that adopting an EF improves movement efficiency. In contrast, aF seems to rather enhance (intrinsic) motivation. However, monetary reward did not further amplify performance. **Key Words:** COUNTERMOVEMENT JUMP, MOVEMENT EFFICIENCY, INTRINSIC, EXTRINSIC, MOTIVATION

It is well known that motor performance can be improved by augmented feedback (aF) (19,31). Augmented feedback is defined as feedback from an external source and can be provided as knowledge of result (KR) or knowledge of performance (KP). Whereas the former provides information about the movement outcome (feedback about goal achievements), the latter informs about the quality of the movement execution. It has to be noted that aF is solely effective when the information is nonredundant and, therefore, provides additional information to the intrinsic feedback (21). Augmented feedback is not only effective when applied in the long term, that is, during several weeks of training (18,23,24), but it can also result in immediate (or short-term) performance gains (7,12). With respect to jumping, it has recently been demonstrated that 4 wk of plyometric training with aF about the achieved jump height (KR) led the participants to better performances than training without feedback (15). Furthermore, the more frequent the aF was provided, the more the participants increased their jump height. Besides these long-term training adaptations, immediate short-term effects were reported. The authors asked half of the participants to perform the first 10 jumps with aF, followed by 10 trials without aF. In the first sequence with aF, jump height was significantly higher than in the second sequence without aF, and an immediate drop in performance was reported as soon as aF was removed. In the second half of the participants, starting without aF followed by jumps with aF, already the first jump with aF was significantly higher than the last one without aF. These observations confirm and extend previous studies reporting instantly increased force/torque levels as soon as participants received aF during maximal force tasks (7,12,25). Thus, aF can be regarded as a powerful tool to increase motor performance in the short term. The mechanism underlying these immediate performance gains was speculated to rely predominantly on motivational factors (15,24) as adaptations occurred instantly as soon as aF was provided and withdrawn, respectively, leaving no time for a learning process. Augmented feedback might enhance motivation by encouraging participants to outplay their foregoing or maximal performance. This comparison with the own foregoing performance is believed to enhance the intrinsic motivation (32).

In contrast to aF, monetary reward (RE) is dictated by external sources and, therefore, considered to act on extrinsic motivation (28). So far, there are no studies in the context of jumping that evaluated the influence of RE on performance. However, it has been shown that RE can lead to short-term performance enhancements in cognitive tasks (2,13,22),

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motor tasks (17,29), and motor learning (1,9). For example, studies showed that hand grip force increased when monetary incentives were enhanced and was decreased when the reward was reduced (26,29,30). However, there are also studies showing that RE may hinder intrinsic motivation and reduce performance (4,6). Thus, the results are less consistent than for aF. Furthermore, there is evidence that intrinsic motivation is favorable over extrinsic motivation (32) so that we hypothesized that aF (intrinsic motivation) leads to better performance outcomes than RE (extrinsic motivation).

However, there are ways to instantly improve motor performance without influencing motivational factors. Adequate instructions about the focus of attention also have been shown previously to be effective (for review, see: 35). More specifically, an external focus of attention (EF), where the participant directs the attention to the effects of his or her movement, is generally superior compared with a neutral condition (NE) or an internal focus of attention (IF), where attention is directed to the performer's body. The potential underlying mechanism for this performance increase is formulated in the constrained action hypothesis, which states that movements are controlled (more) automatically when adopting an EF (37). This leads to better performances while, at the same time, muscular activity is reduced and results therefore in a more efficient movement execution (for review, see: 35). With respect to jumping, several studies have demonstrated superior performance (27,34,38) and reduced muscular activity (36) with EF compared with IF or NE. Recently, the effects of IF, EF, and aF on jump performance have been compared (16). In line with previous observations, EF resulted in better jump heights than IF. However, aF was considerably superior to enhancing jump height than EF. In the present study, we therefore tested whether the mechanisms of EF are still working when combining it with other performance-enhancing approaches to provoke superior outcome.

In summary, aF, RE, and EF probably rely on different mechanisms, the former two on intrinsic and extrinsic motivation, respectively, and the latter one on movement efficiency. The present study therefore tested the combination of these different performance-enhancing approaches. For this purpose, we combined aF with EF and/or RE to identify the most powerful instruction to instantaneously improve and maximize jump performance. It was hypothesized that the combination of largely independent mechanisms should provoke additional beneficial effects, that is, higher jump heights. With the above-presented literature as basis, we assumed best performance outcome when combining aF and EF as aF should positively influence intrinsic motivation and EF should improve movement efficiency.

METHODS

Participants

Eighteen adults (26.6 ± 8.9 yr, 1.74 ± 0.09 m, 71.4 ± 12.7 kg; eight female and ten male subjects) without any neurological and/or orthopedic injuries participated in this study. Participants were generally athletic. However, none of them reported that jumping was part of their workout routine. Before testing, all participants read the information sheet explaining the applied methods and devices and gave written informed consent. The experimental procedure respected the latest declaration of Helsinki and was approved by the Ethics Commission of the Canton of Fribourg. Participants were naive to the purpose and hypotheses of the study.

Experimental Protocol

After a standardized 10-min warm-up (jogging and hopping), participants watched a video of a well-trained athlete performing a countermovement jump (CMJ) for familiarization with the jumping procedure. Additionally, participants performed 6 to 8 CMJs where they were told to jump as high as possible with maximum effort in each jump. Participants were instructed to jump with their arms akimbo and to keep the jumping procedure similar throughout the entire experiment.

The protocol included 16 series of six maximal CMJs allocated to the following six conditions: NE, aF, RE, aF + EF, aF + RE, and aF + EF + RE. Each condition was repeated twice, except the NE condition (6 repetitions), and the order was randomized for each participant. The only exception to this randomization was the NE condition that was evenly distributed throughout the experiment. Furthermore, two NE series at the beginning were not used for further analysis as they served as a reference for the reward condition. Similarly, the NE series at the end was not included in the main analysis but served as a control for fatigue. Breaks of 10 s between two consecutive jumps and of 2 min between series were integrated. Before and in the middle of each series, verbal instruction of the current condition was given to the participants. For the different conditions, the following instructions were used:

NE: "Jump as high as possible."

aF: "Jump as high as possible. After each jump, you can see your jump height on the screen."

RE: "Jump as high as possible. The higher you jump, the more money you will get."

aF + EF: "Jump as high as possible while concentrating on pulling out as much cord as possible. After each jump, you can see your jump height on the screen."

aF + RE: "Jump as high as possible. The higher you jump, the more money you will get. After each jump, you can see your jump height on the screen."

aF + EF + RE: "Jump as high as possible while concentrating on pulling out as much cord as possible. The higher you jump, the more money you will get. After each jump, you can see your jump height on the screen."

Conditions

External focus. For the external focus condition, a cord was fixed to the lower back of the participants. The cord went down to the floor, was there deviated by 90°, and went along the floor horizontally to the cord spindle, which was placed 2 m behind the back of the participants. When jumping, the cord was pulled out of the spindle with a quiet tone so that

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participants got no additional information about their performance. After each jump, the cord was furled manually.

Augmented feedback. For all aF conditions, a light barrier beside the force plate was used to determine flight time. Based on this, jump height was calculated and displayed on a screen as aF. Please note that the jump heights used for all further analysis were calculated based on the data of the motion capture system (Vicon), as this is considered to be highly reliable (5).

Monetary reward. The amount of the monetary reward was calculated in proportion to the achieved mean jump height of the two NE series at the beginning of the experiment (baseline). During all RE conditions, participants were not aware of how much money they earned with their jumps because they did not know the value of their baseline measures. Therefore, the RE approach did not provide the participants with additional information, that is, augmented feedback, about their performances during the experiment.

Measurements and Analysis

Electromyography. Muscular activity was recorded in M. gastrocnemius medialis, M. tibialis anterior, M. rectus femoris, M. vastus medialis, and M. biceps femoris of the right leg with a custom-built electromyography (EMG) system (EISA, University of Freiburg, Germany). Skin preparation and electrode (Blue Sensor P, Ambu A/S, Ballerup, Denmark) placement were done respecting the SENIAM guidelines (11). A Velcro strap reference electrode was placed around the shank. Interelectrode impedance was kept below 5 kΩ. Before recording, all electrodes were checked for artifacts. EMG data were amplified (1 kHz), bandpass filtered (10–1000 Hz), and sampled at 4 kHz. For recordings, a custom-built software (LabView based, National Instruments, Austin, TX) was used. EMG activity was analyzed offline with MatLab (Version 2014b; The MathWorks, Inc., Natick, MA). Onset of muscle activity was defined as start of the first 20 ms window in which all data points were above 10% of the maximum EMG activity. The root mean square (RMS) value of EMG signal was subsequently calculated for the entire time between onset of muscle activity and takeoff.

Kinetic data. A 508 × 464 mm force plate (OR6-7, Advanced Mechanical Technology Inc., Watertown, MA) was used for the analysis of vertical ground reaction forces (vGRF). The kinetic data were sampled at 4 kHz. Vertical ground reaction forces were analyzed offline with MatLab. Values below 5 N were considered to represent the flight phase. Time points for takeoff and landing were determined as the beginning and the end of the flight phase. In the second before takeoff, the maximum peak (F_{max}) of the vGRF was assessed, as well as the time point when F_{max} occurred (tF_{max}). Based on these data, the force production per time (F_{max} /t) was calculated by dividing F_{max} by tF_{max} ($F_{max}/t = F_{max}/|tF_{max}|$).

Kinematic data. A Vicon 512 System (Vicon Motion Systems Ltd., Oxford, UK) with 6 cameras was used for the analysis of jump height, joint angles, and time variables of the movement. Markers were placed on toe, metatarsus, ankle, knee, trochanter major, and hip of the right leg. Kinematic data were sampled at 120 Hz and analyzed offline with MatLab. Takeoff was defined as the first vertical movement of the toe marker. Maximal jump height was calculated by subtracting the height of the hip marker in normal upright stance from the maximal height of the hip marker during the jump. Furthermore, maximal angles (ANG_{max}) for ankle, knee, and hip during the stretch-shortening cycle were calculated, and the time ($tANG_{max}$) between ANG_{max} and takeoff was determined for all three angles.

Statistics. For each variable, the different conditions were compared using one-way repeated measures ANOVA. If sphericity was violated (Mauchly's sphericity test), the degrees of freedom were adjusted with the Greenhouse–Geisser correction. Significant *F* values ($P < 0.05$) were followed up using *post hoc* pairwise comparisons (Bonferroni-corrected Student's *t* tests). Furthermore, effect sizes are presented as partial eta square values (η^2_p; small effect: 0.02; medium effect: 0.13; large effect: 0.26). SPSS (Version 21.0; IBM, Armonk, NY) was used for all statistical analysis. Data are presented as group mean values ± standard deviation, if not otherwise indicated.

RESULTS

Participants showed the highest jump heights with aF + EF (39.30 ± 6.66 cm) and, as expected, the lowest in the NE condition (38.15 ± 7.05 cm; Fig. 1 and Table 1). A one-way repeated-measures ANOVA revealed significant differences between conditions ($F_{5,85} = 9.092$; $P < 0.001$; $\eta^2_p = 0.348$). *Post hoc* analysis with Bonferroni-corrected *t* tests (by the factor of 15) indicated significant differences between NE and aF + EF ($P < 0.001$), NE and aF + EF + RE ($P = 0.005$), and between NE and aF + RE ($P = 0.044$). Furthermore, aF + EF was significantly superior to aF alone ($P = 0.014$) and RE alone ($P = 0.014$). In addition, comparison of the aF condition and the NE condition revealed a significant difference ($P = 0.020$), but only when the *t* test was not Bonferroni-corrected (i.e., by

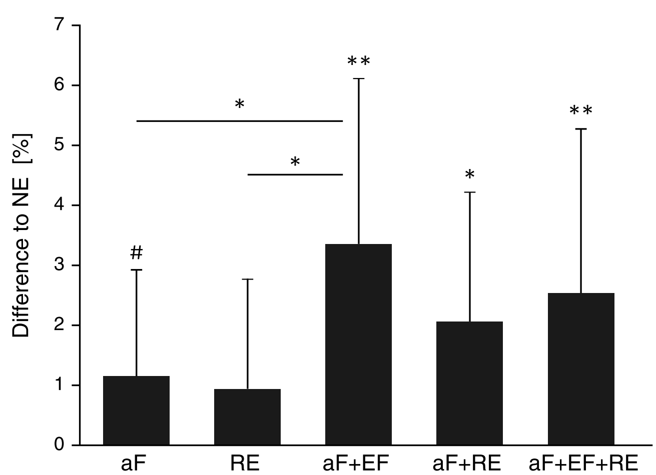

FIGURE 1—Jump heights for the different conditions. Values are expressed as percentage differences to the NE condition and are displayed as mean and standard deviation. *P < 0.05; **P < 0.01 (Bonferroni-corrected) and #P < 0.05 (uncorrected). NE indicates neutral; aF, augmented feedback; RE, monetary reward; EF, external focus.

TABLE 1. All measured parameters for the six different conditions.

	NE	aF	RE	aF + EF	aF + RE	aF + EF + RE
Jump height (cm)	38.15 ± 7.05	38.51 ± 6.76****	38.47 ± 6.92	39.30 ± 6.66*,**,***	38.90 ± 7.00*	39.07 ± 7.11*
F_{max} (N)	1563.54 ± 326.51	1582.40 ± 324.03	1573.47 ± 314.09	1559.04 ± 309.57	1591.00 ± 330.04	1568.95 ± 316.47
tF_{max} (ms)	289.01 ± 69.06	285.83 ± 70.84	282.45 ± 76.46	282.64 ± 60.47	289.67 ± 69.58	279.40 ± 72.46
F_{max}/t ($N \cdot ms^{-1}$)	5.79 ± 2.07	5.89 ± 1.88	6.12 ± 2.50	5.75 ± 1.56	5.94 ± 2.31	6.23 ± 3.06
ANG_{max} ankle (°)	25.06 ± 7.87	25.49 ± 7.80	25.17 ± 7.57	25.52 ± 7.42	25.36 ± 7.72	25.69 ± 7.20
$tANG_{max}$ ankle (ms)	261.85 ± 80.66	258.07 ± 60.93	260.51 ± 71.80	249.70 ± 61.35	258.74 ± 69.22	249.99 ± 77.49
ANG_{max} knee (°)	85.91 ± 10.69	85.58 ± 9.91	85.46 ± 9.89	84.39 ± 9.57	85.42 ± 10.55	84.95 ± 10.62
$tANG_{max}$ knee (ms)	279.45 ± 43.09	272.98 ± 38.44	275.32 ± 38.09	268.61 ± 32.85	274.70 ± 42.41	271.20 ± 41.11
ANG_{max} hip (°)	93.75 ± 17.95	93.28 ± 18.21	93.19 ± 17.92	92.77 ± 17.99	93.28 ± 17.83	93.30 ± 17.59
$tANG_{max}$ hip (ms)	342.13 ± 47.67	335.86 ± 40.83	339.81 ± 41.89	330.47 ± 36.31	337.02 ± 43.20	333.80 ± 39.75
RMS M. gastro medialis (mV)	0.22 ± 0.11	0.22 ± 0.11	0.22 ± 0.10	0.22 ± 0.11	0.22 ± 0.11	0.22 ± 0.10
RMS M. tibialis anterior (mV)	0.12 ± 0.09	0.12 ± 0.09	0.12 ± 0.09	0.13 ± 0.09	0.12 ± 0.09	0.13 ± 0.10
RMS M. rectus femoris (mV)	0.25 ± 0.08	0.25 ± 0.08	0.25 ± 0.08	0.24 ± 0.07*	0.25 ± 0.08	0.24 ± 0.08*
RMS M. biceps femoris (mV)	0.18 ± 0.06	0.17 ± 0.05	0.17 ± 0.06	0.18 ± 0.05	0.18 ± 0.07	0.18 ± 0.06
RMS M. vastus medialis (mV)	0.38 ± 0.14	0.37 ± 0.14	0.37 ± 0.14	0.36 ± 0.14	0.37 ± 0.14	0.37 ± 0.14

Values are expressed as mean and standard deviation. *$P < 0.05$ versus NE; **$P < 0.05$ versus aF; ***$P < 0.05$ versus RE (all Bonferroni-corrected) and ****$P < 0.05$ versus NE (uncorrected). NE indicates neutral; aF, augmented feedback; RE, monetary reward; EF, external focus; F_{max}, ground reaction force peak; tF_{max}, time between F_{max} and takeoff; F_{max}/t, F_{max} divided by tF_{max}; ANG_{max}, maximal joint angle; $tANG_{max}$, time between ANG_{max} and takeoff; RMS, root mean square.

the factor of 15) as were the other *t* tests. We provide this uncorrected *P* value nevertheless to make comparisons with previous studies in which fewer conditions were tested, and thus, *post hoc* correction values were much lower or even not necessary.

The influence of fatigue was controlled by comparing the first two (baseline) and the last NE series. As the last NE series, performed at the end of the measurements, was not lower than the baseline, fatigue effects can be excluded.

The analysis concerning F_{max} revealed no significant differences between conditions ($F_{3.06,52.04} = 2.247$; $P = 0.093$; $\eta^2_p = 0.117$). Furthermore, no significant results were found for tF_{max} ($F_{3.28,55.71} = 1.055$; $P = 0.380$; $\eta^2_p = 0.058$) and for F_{max} /t ($F_{1.49,25.25} = 0.965$; $P = 0.370$; $\eta^2_p = 0.054$; Table 1).

No significant differences between conditions were found for ANG_{max} as well as $tANG_{max}$ for all three analyzed angles (Table 1).

When analyzing muscular activity, M. rectus femoris showed significant differences between conditions ($F_{3.43,58.27} = 3.797$; $P = 0.011$; $\eta^2_p = 0.183$; Fig. 2). *Post hoc* analysis revealed significantly reduced activity in the aF + EF ($P = 0.049$) and the aF + EF + RE condition ($P = 0.001$) compared with NE. For all other muscles, no differences between conditions were found. Furthermore, for each muscle, the onset of muscle activity was similar across conditions.

DISCUSSION

Augmented feedback has recently been shown to improve jump performance in the short and long term compared with a condition without feedback (i.e., NE) (15). In contrast to this observation and findings obtained in force tasks (7,12), aF did not result in significant performance gains compared with the NE condition in the current study. However, it has to be stated that previous studies (7,12,15) tested solely aF against NE, whereas in the present study, 6 conditions (four of them containing aF) were tested against each other. This multiple condition design may have weakened the impact of the single aF condition compared with NE. Furthermore, the Bonferroni corrections for multiple comparisons were considerably higher ($n = 15$) than in those previous studies. Hence, the uncorrected test ($P = 0.020$) is nevertheless displayed to show congruence with previous work with fewer conditions.

When participants received RE, jump height was almost as high as in the aF condition. However, there was no significant difference compared with the NE condition, even without Bonferroni correction. Thus, the effect of RE was not as consistent and revealed greater interindividual differences than provision of aF. It has previously been shown that a monetary incentive can enhance the effort but does not necessarily improve the performance outcome (3). Thus, it might be speculated that some participants increased both effort and performance outcome while others could not translate increased effort into improved performance. Nevertheless, we cannot exclude that the monetary incentives that were given to the participants were too low (at least for some of the participants) to provoke performance enhancements. The maximal monetary reward was just below

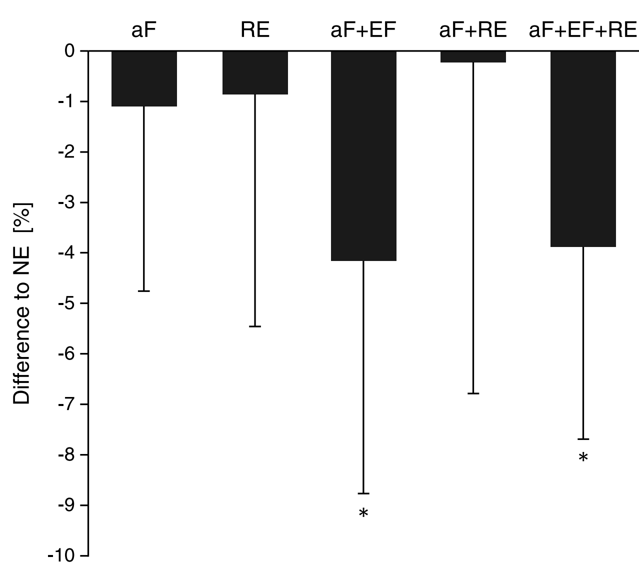

FIGURE 2—Root mean square (RMS) of *M. rectus femoris* activity from onset of muscle activity to takeoff for the different conditions. Values are expressed as percentage differences to the NE condition and are displayed as mean and standard deviation. *$P < 0.05$. NE indicates neutral; aF, augmented feedback; RE, monetary reward; EF, external focus.

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the level of an average hourly wage, and it is known that higher monetary rewards provoke better outcomes (26,29,30).

Importantly, in contrast to most previous studies using monetary incentives (1,9), the RE condition in the current study provided no information about the quality of each single trial as participants were informed about their monetary gain only after the experiment. Thus, they did not receive information about which trial was successful and which trial was not. Our results are therefore in line with a study testing well-trained cyclists in a 1500-m time trial (14), where feedback was also provided only after the trial. In this study, no improvement in performance was found in the monetary reward condition. This may explain the quite pronounced improvements when adding aF to the monetary incentive (aF + RE). As soon as participants were enabled differentiating good from less good trials, there was a significant difference compared with the NE condition. Our data therefore suggest that only the combination of aF + RE generates superior outcome, whereas RE alone, without directly informing the participant about good and less good trials, does not improve motor performance. Furthermore, these results stress the importance of disentangling the "pure" influence of RE (i.e., receiving the reward only at the end of the experiment) from the "intermingled" influence of RE and binary feedback (i.e., receiving RE directly after each trial).

When combining aF with EF instead of RE, the highest jump heights were realized. Furthermore, aF + EF was the only condition that showed significantly superior performances compared with aF and RE alone. To our knowledge, the combination of aF and EF has never been tested before, although it is well known that both conditions are well suited to immediately enhance performance (19,35). With respect to jumping, a recent study has compared the effects of aF and EF (16). The authors demonstrated that both conditions increased performance compared with an internal focus of attention. However, aF was more effective than EF. The current results demonstrate that the combination of aF and EF is even more efficient and therefore seems to be the best way to boost performance in the short term, especially as there was no further increase when aF + EF was combined with RE (aF + EF + RE). This latter result may be explained by the fact that when instructing the aF + EF + RE condition, participants had to think about 3 different approaches at the same time. Maybe this was too much information to process simultaneously and may therefore have undermined maximal performance enhancement (cf. 8).

The Role of Motivation

The motivation of an athlete can have an eminent impact on his performance (10). It can be differentiated between intrinsic and extrinsic motivation. In the present study, aF was considered as an intrinsic motivator as we assume that participants tried to outplay their foregoing jump height. This view might be argued to be in contrast to the assumption that aF provides relevant information to improve performance by allowing short-term learning/adaptation: in this way, aF may inform about task execution so that participants are encouraged to either continue or to modify their movement patterns (7). With respect to jumping, the latter was recently shown to be unlikely as immediate performance drops can be observed as soon as aF is removed (15). Thus, aF seems to rather act on motivation than on learning in the short term—at least in tasks that are familiar to the participant and where the goal is to maximize performance. The superior performance in all conditions with aF compared with NE in the current study support this assumption. If participants would have had learned a certain movement pattern with aF, there should have been "carryover effects" to the NE condition, which was obviously not the case.

In contrast to aF, monetary incentives can be clearly declared as an extrinsic motivator. Generally, the conditions including the RE approach did not produce better jumping performances than comparable conditions in the present study (Fig. 1). This finding is in line with observations of Hulleman and colleagues (14), who found no performance increase in the RE condition. It has previously been shown in psychological and economic research that extrinsic monetary rewards can undermine intrinsic mechanisms and therefore hinder performance enhancement (4,6). This was not the case in the present study as jump heights did not decrease in the conditions with RE. Thus, the extrinsic motivator in monetary form had only marginal influence on performance outcome in the current study.

Movement Efficiency through an External Focus of Attention

The enhanced jump performance in aF + EF and aF + EF + RE indicates a positive impact of the EF approach. As can be seen in Figure 2, participants activated their M. rectus femoris significantly less in the two conditions with EF. Furthermore, the M. vastus medialis also showed decreased activity in the aF + EF and aF + EF + RE conditions, however, only without Bonferroni correction. This finding of reduced muscular activity despite better performance is in line with previous studies, where muscular activity was generally reduced and performance was increased when adopting an EF (20,33,36). Our study illustrates for the first time that combining an EF with other factors such as aF still results in a more efficient movement execution and superior performance outcome.

CONCLUSIONS

This is to our knowledge the first study comparing combinations of aF, EF, and RE. The combination of aF and EF demonstrated the largest enhancements in jump performance. We assume that this results from additive benefits of two largely independent mechanisms: aF mainly acting on (intrinsic) motivation and EF improving movement efficiency. From a functional point of view, this finding may not only be important to maximize jump performance but may be transferred to many other sports disciplines as well.[8]

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