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Published online: 12 Apr 2016.

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The effects of two different correction strategies on the snatch technique in weightlifting

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ABSTRACT

Improving motor skills represents one of the major issues in motor control and motor learning literature. The aim of this study was to investigate which of two strategies, method of amplification of error (MAE) or direct instruction (DI), would be more beneficial for error correction of the snatch technique. Thirty well-trained male weightlifters were randomly assigned to one of three training conditions (MAE, DI and Control). The experiment took place in only one practice session in which each lifter performed 3 pretraining trials, 8 training intervention trials, and 3 post-training trials, and a retention test session after 1 week. An optoelectronic motion capture system was used to measure the kinematic parameters of the weightlifting performance. After the training intervention, data showed that the MAE group revealed a greater improvement in several kinematic parameters when compared to the DI and Control groups, and the benefits derived from its application were still present 1 week later in the retention test. Nevertheless, the findings of the present study should be interpreted with caution due to the relatively small sample size; further research will also be necessary to evaluate the effects of MAE with different ability levels and other sport skills. The present findings could have practical implications for sport psychology and physical education because while practice is obviously necessary for improving learning, the efficacy of the learning process is essential in enhancing learners' motivation and sport enjoyment.

Introduction

The aim of training in weightlifting is to develop a technique that enables athletes to lift heavy weights. To reach the best possible technique, coaches and biomechanists isolate and correct the errors in techniques that may hinder performance and increase the risk of injury. However, these errors are not easy to identify. It is known that all motor skills present a number of constraints related to the skill task. These include the individual's body characteristics, their personal style and environmental constraints. Understanding them is a valuable tool to increase the effectiveness of learning interventions (Williams, Irwin, Kerwin, & Newell, 2014). Unfortunately, to date, there has been very little study into the effects of different feedback protocols on the development of good weightlifting technique.

In sport science, traditional methods of coaching and the correction of technical errors are based on delivering direct verbal instruction through descriptive or prescriptive feedback. Research conducted on feedback has focused predominantly on knowledge of results after relatively good or relatively poor trials (Badami, VaezMousavi, Wulf, & Namazizadeh, 2011; Chiviacowsky & Wulf, 2007; Saemi, Porter, Ghotbi-Varzaneh, Zarghami, & Maleki, 2012), and only recently the knowledge of performance has been evaluated. The few studies which have investigated the effects of feedback on the snatch and clean techniques demonstrated an improvement in bar kinematics after receiving verbal and visual augmented feedback (Rucci & Tomporowski, 2010; Winchester, Porter, & McBride, 2009).

In general feedback literature, one factor influencing motor skill learning is the individual's focus of attention induced by either the instructions or feedback (Wulf, Höß, & Prinz, 1998; Wulf & Su, 2007; Zentgraf & Munzert, 2009). These authors affirmed that instructions inducing an external focus of attention (i.e., focus on the movement effects) were more effective than those inducing an internal focus (i.e., focus on the movements themselves).

Over the last decade, a different type of feedback has been proposed based on the assumption that practicing motor errors can actually strengthen motor learning (Chen, Pei, Chan, & Yan, 2012; Milanese, Corte, Salvetti, Cavedon, & Agostini, in press; Milanese, Facci, Cesari, & Zancanaro, 2008; Milot, Marchal-Crespo, Green, Cramer, & Reinkensmeyer, 2010). In particular, the method of amplification of error (MAE), put forward by Milanese and colleagues (Cesari & Milanese, 1995, Milanese et al., 2008, in press), is based on the assumption that individuals can learn to correct their own movements through an exploration of their mistakes. The concept behind MAE is that movements are stored and reproduced by following rules regulated through the mastering of body constraints and degrees of freedom during the actual performance (Bernstein, 1967) and

Table 1. Characteristics of the groups.

Group	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Experience (years)	W_Comp (kg)
MAE ($n = 10$)	23.2 (12.6)	171.7 (7.6)	81.0 (20.1)	27.5 (4.4)	7.4 (4.5)	74.6 (20.0)
DI ($n = 10$)	24.7 (9.5)	167.3 (9.5)	73.5 (13.5)	26.3 (1.9)	7.5 (5.8)	75.7 (16.7)
C ($n = 10$)	23.8 (10.7)	172.0 (8.7)	80.7 (19.3)	27.3 (3.8)	8.4 (9.1)	72.8 (21.7)

Data are presented as mean (standard deviation).
MAE: method of amplification of error; DI: direct instruction; C: control; W_Comp: best weightlifted during the last competition.

not by storing numerous central motor programmes for all possible classes of movements (Adams, 1971).

Motor adaptation involves the use of constant error information from the nervous system to make improvements on movement. According to previous studies, the rate of motor learning is proportional to the motor errors experienced (Kawato, 2002; Scheidt, Dingwell, & Mussa-Ivaldi, 2001; Thoroughman & Shadmehr, 2000). Forced exaggeration of the error helps the learner to make useful comparisons between their usual movement and the amplified error movement. This comparison allows the learner to understand the effects of the error on the outcome and modify his movement accordingly. In other words, the amplified error movement guides the learner to focus their attention on the movement effects and not on the movement itself. In fact, other studies regarding attentional focus and motor learning (Wulf et al., 1998; Wulf & Su, 2007) have stated that instructions inducing an external focus of attention, like the effects of an amplified error, were more effective than internal focus instructions.

The aim of the present work was to investigate the learning advantages of MAE compared with direct instruction (DI), specifically whether the previous findings (Milanese et al., 2008, in press) could be generalised to a sport where a complex balance of physical conditioning and skill technique are necessary. In this work, we compared MAE with DI and a control group (C) by testing the effects of these methods on the correction of technical errors in snatch performance. We also evaluated the persistence of improvement over time.

An innovative aspect of this study was the combination of qualitative observation and quantitative measurement of performance to demonstrate the effectiveness of the error correction comparing two different types of instruction on a complex skill such as weightlifting. Biomechanical qualitative analysis of the snatch technique was used to measure the performance in greater detail with the intention of bridging the gap between quantitative and qualitative analysis made by the coach.

Methods

Participants

Thirty well-trained male weightlifters (*M* age = 23.9 years, SD = 10.5) were randomly placed in one of three training conditions: MAE condition, with error amplification feedback; DI condition, with prescriptive and descriptive feedback and C condition, without feedback. Participants were informed that the aim of the study was to examine learning in the snatch technique, but were not told about the different group interventions.

Participants trained five times a week for 15 h/week and they were involved in competitions at the regional and national level. The anthropometric data, experience and weightlifting performance data are presented in Table 1.

The study had full ethical approval and all participants gave their written informed consent.

Procedure

The experiment included a practice session and a retention test after 1 week. Between the practice session and retention test, all participants maintained their usual training activity. Before the practice session, a professional coach was involved in qualitative analysis of the movement.

According to Bartlett (2007), determining the performance criteria, determining the mechanical factors affecting performance and identifying the critical features are all fundamental in error diagnosis. In the present study, the professional coach defined the critical features of the snatch prior to the diagnosis stage using all of the biomechanical research material available at present.

Previous studies (Hoover, Carlson, Christensen, & Zebas, 2006; Schilling et al., 2002) have established a number of important kinematic factors that contribute to successful snatch technique: horizontal (rearward) displacement of the bar in the first pull with respect to the starting position (Dx2); the amount of looping of the bar in the catch phase (DxL); the ratio of looping to the net rearward displacement of the bar (DxL ratio to DxT) and the maximum vertical linear velocity of the barbell. During the snatch, the trajectory of the barbell is usually an S-shaped pattern: the bar should be moved towards the lifter during the first pull and transition phase, and then it is pushed away from the lifter's body by the hip and knee joint extensions and shoulder flexions (Chiu, Wang, & Cheng, 2010). Nowadays, several studies have established the ideal bar path for proper weightlifting technique, with particular attention to reducing the horizontal displacement to improve technique and in turn to increase power and force production (Harbili & Alptekin, 2014; Winchester et al., 2009). Some authors state that a small anterior–posterior displacement of the barbell reduces loss of energy (Gourgoulis, Aggelousis, Mavromatis, & Garas, 2000; Isaka, Okada, & Fuanto, 1996; Stone, Pierce, Sands, & Stone, 2006). The professional coach in this study considered these critical features in the diagnosis stage to identify the most influential error for task performance, called the "selected error". According to previous studies (Corte, Cavedon, & Milanese, 2015; McPherson, 1990), errors can be classified according to their importance on the final outcome of the movement. One such error in particular may primarily effect performance outcome and increase the risk of injury.

Table 2. Selected errors diagnosed and feedback delivered for the two training conditions (MAE and DI).

	At start position	At first pull
Selected error	The weightlifter's chest was behind the bar (towards the heels).	The weightlifter did not move the bar towards his body during the first pull and/or the transition phase.
MAE feedback	"Move your chest behind the bar as far as possible at the start position".	"Move the bar forwards as far as possible while performing the first pull".
DI feedback	"Your chest was too far behind the bar, keep your chest over the bar as far as possible at the start position".	"You did not move the bar towards your body, move the bar towards your body as far as possible while performing the first pull".

MAE: method of amplification of error; DI: direct instruction.

The coach was unaware during this phase of the three final grouping conditions that the participants would randomly be assigned to. As qualitative analysis was performed by a single coach, 10 trials for each participant were video-recorded through a high-speed video camera (100 Hz; Casio Exilim EX-ZR 1000) similar to previous research (Bartlett, 2007). For a detailed assessment of technical errors and intra-observer reliability, the coach analysed the video three times, with 3 days between each viewing.

Table 2 summarises the "selected errors" identified during the preselection phase.

Practice session

Prior to the practice session, the participants performed a self-selected warm-up that included various dynamic stretching exercises and submaximal weightlifting movements, for example, squat movements and snatch movements with just the bar and with gradual weight increases. During the practice session, each athlete performed 14 trials as follows: 3 pretraining trials (T_0), 8 training intervention trials and 3 post-training trials (T_1). In the pretraining and post-training trials participants were simply asked to "do their best". In the training intervention trials, both the MAE and DI groups received their respective feedback from the professional coach, whereas the C condition group performed the trials without receiving any feedback and were simply asked to "do their best" throughout. The trials were performed individually to avoid communication between participants. The professional coach delivered feedback through verbal instructions using standardised phrases that were decided before the trials. In order to avoid a long description, which could "confuse" the participant, the verbal instructions were formulated using very few words (Table 2).

The average rest time between trials was approximately 2 min. Each athlete performed the trials at 80% of the maximum weightlifted in the last competition with the snatch technique (Table 1).

Error amplification condition
The MAE procedure included the following steps: (a) the "constrained trial": the weightlifter was asked to perform the snatch with instructions that would cause exaggeration of his mistake without him knowing (Table 2). In this trial, it was very important that the participant exaggerated the error diagnosed by the coach as much as possible. It has been suggested that forced exaggeration helps learner make

fruitful comparisons between movements, and thus better perceive the effects of the error on his movement (Milanese et al., 2008, in press). (b) The "free trial": the weightlifter was asked to perform the movement freely without any constraints. Steps (a) and (b) were repeated four times in an alternating sequence. Therefore, trials 1-3-5-7 incorporated error feedback, and trials 2-4-6-8 involved no feedback and were simply asked to "do their best".

DI condition
The DI procedure included the following steps: (a) the "constrained trial": the weightlifter was asked to perform the movement following the corrective feedback given through DI. In this study, the professional coach explained what had been done wrong and provided information that could be used to correct the movement through prescriptive feedback (Table 2). (b) The "free trial": the weightlifter was asked to perform the movement freely without any constraints. Steps (a) and (b) were repeated exactly as in the error amplification condition.

Control condition
The lifters performed 8 trials without receiving any feedback and were simply asked to "do their best" throughout.

Retention test

The second session for all participants took place 1 week later to assess skill retention. During this session, each weightlifter performed 10 trials without receiving any feedback and was simply asked to "do their best".

Apparatus

Kinematic measurements were made in the biomechanics laboratory at the University in the presence of the professional coach. Three dimensional kinematic data were collected using an eight-camera optoelectronic motion capture system (MX Ultranet, VICON, Oxford, UK) using Nexus software (Nexus 1.7.1) with a sampling frequency of 250 Hz. Calibration of this system was performed according to the manufacturer's guidelines. Thirty-nine retro-reflective passive markers were placed over specific anatomical landmarks on the participant's body to define the kinematic model and to create a stick figure that was used for visualisation (Figure 1). Two additional markers were placed on the ends of the barbell and used to visually identify the barbell's trajectory during the data analysis. Vicon BodyBuilder software 3.1.1 (Oxford Metrics Group,
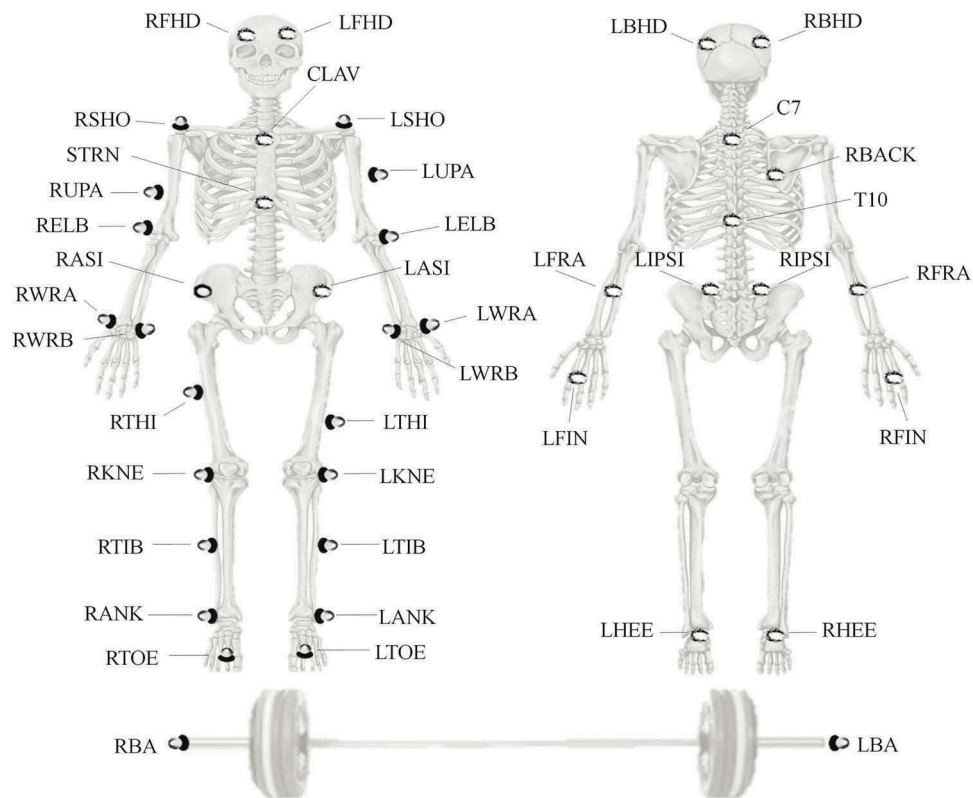
Figure 1. Markers set: LFHD: left front head; RFHD: right front head; LBHD: left back head; RBHD: right back head; C7: 7th cervical vertebrae; T10: 10th thoracic vertebrae; CLAV: clavicle; STRN: sternum; RBACK: right back; LSHO: left shoulder; RSHO: right shoulder; LUPA: left upper arm; RUPA: right upper arm; LELB: left elbow; RELB: right elbow; LFRA: left forearm; RFRA: right forearm; LWRA: left wrist; RWRA: right wrist; LWRB: left wrist; RWRB: right wrist; LFIN: left fingers; RFIN: right fingers; LASI: left anterior superior iliac spine; RASI: right anterior superior iliac spine; LPSI: left posterior superior iliac spine; RPSI: right posterior superior iliac spine; LKNE: left knee; RKNE: right knee; LTHI: left thigh; RTHI: right thigh; LANK: left ankle; RANK: right ankle; LTIB: left tibial wand; RTIB: right tibial wand; LTOE: left toe; RTOE: right toe; LHEE: left heel; RHEE: right heel; RBA: right extremity of the barbell; LBA: left extremity of the barbell.

Oxford, UK) was used for digitalisation, reconstruction and processing of the marker positions.

Data analysis

Row 3D kinematic data were filtered using a low-pass Butterworth filter (fourth order) with a cut-off frequency of 6 Hz (Winter, 2005). Data analysis was executed with a custom program written in Matlab R2008a (MathWorks, Natick, MA).

The analysis focused on the snatch technique from the beginning of the barbell lift-off to the instant at which the lifter dropped under the barbell and caught the barbell overhead. The movement was divided into five phases (Figure 2), according to the change in direction of movement of the right knee angle (Campos, Poletaev, Cuesta, Pablos, & Carratala, 2006) and the height of the barbell:

- *The first pull*: from the barbell lift-off until the first maximum right knee extension.
- *The transition between the first and the second pull*: from the first maximum right knee extension until the first maximum right knee flexion.
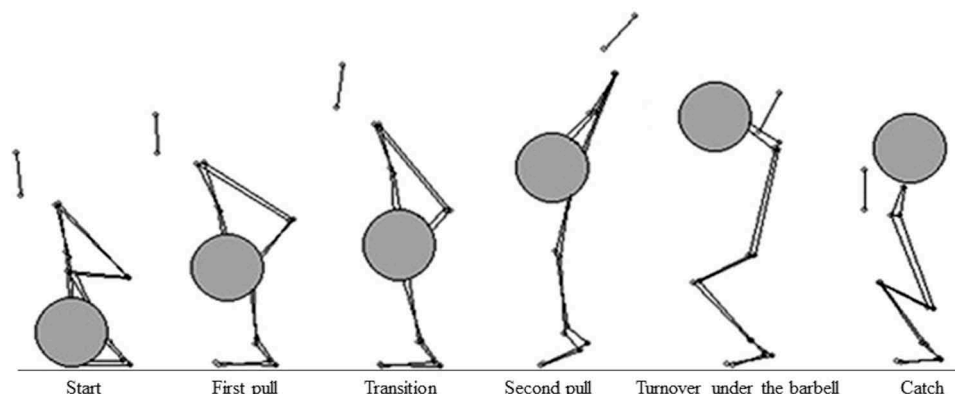

Figure 2. The phases of the snatch.

Start   First pull   Transition   Second pull   Turnover under the barbell   Catch

- *The second pull*: from the first maximum right knee flexion until the second maximum right knee extension.
- *The turnover under the barbell*: from the maximum right knee extension until the point of the maximum height of the barbell.
- *The catch phase*: from the point of the maximum height of the barbell until stabilisation in the catch position with the barbell overhead.

The barbell's movement was analysed through the anterior-posterior displacement of the bar and the maximum height of the bar. Movement of the bar towards the lifter was considered positive horizontal displacement, and movement of the bar away from the lifter was negative (Figure 3). The bar path was assessed using the following linear kinematic parameters: the horizontal displacement (Dx2, DxV, DxT and DxL); the vertical displacement (VTR); the maximal vertical linear velocity of the barbell during the first pull (Vvel_FP) and the maximal vertical linear velocity of the barbell (Max_Vvel). The difference between the right and left sides of the barbell's maximal vertical linear velocity (Diff_Max_Vvel) was also calculated. Data of both the practice session (at T_0 and T_1) and retention test session (at T_2) were analysed.
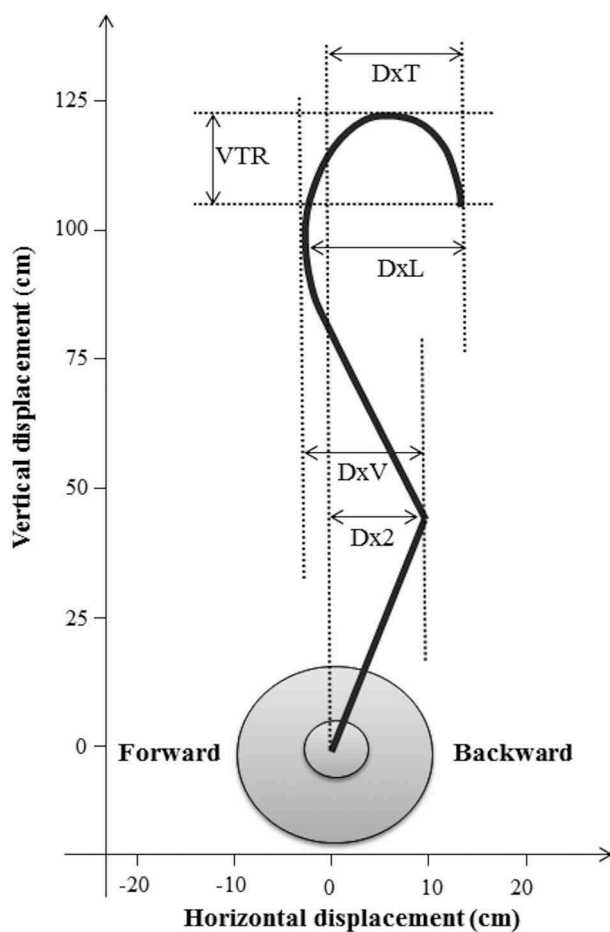

Figure 3. Description of bar path kinematic variables used to assess quantitative changes in bar path at baseline (T0), after training intervention (T1) and retention test (T2).

Statistical analysis

All analyses were performed with SPSS v. 16.0 (IBM Corp., Armonk, NY, USA) and statistical significance was set at $P \leq .05$. Normality of data and equal variance assumptions were checked using the Shapiro–Wilk and Levene tests, respectively. Natural log transformations were used for analysis of variables that did not follow a normal distribution. Baseline data (T_0) of kinematic parameters, age and weightlifting experience were compared using one-way analysis of variance (ANOVA) followed by the post hoc Bonferroni test for multiple comparisons to assess differences within and between groups, respectively. A mixed-design 3 × 3 ANOVA (3 groups: MAE, DI, C and 3 times: T_0, T_1 and T_2) with repeated measures on the second factor was performed to assess the changes over time for each kinematic variable and the between-group differences. When the repeated measures factor violated the assumption of sphericity ($P < .05$), the Greenhouse–Geisser correction which refers to degrees of freedom of F-statistics was required. A Holm–Bonferroni correction was used to minimise type I error (Gaetano, 2013; Holm, 1979) and the family-wise alpha level for all significance tests was set at .05. For each ANOVA model, if significant interactions were detected (group-by-time), they were followed by pairwise comparisons with Bonferroni corrections.

Eta squared (η^2) was used to calculate the effect size in the ANOVA with repeated measures. According to Cohen's guidelines (Cohen, 1988), effect size values were interpreted as small ($\eta^2 = .02$), medium ($\eta^2 = .13$) and large ($\eta^2 = .26$). The post hoc statistical power of the sample was evaluated using G*Power Software 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) on the basis of the observed effect size and alpha value was set at .05.

Results

Descriptive statistics presented as mean (±SD) are summarised in Table 3. At baseline (T_0), within-group comparison revealed no significant difference between MAE, DI and C groups for age, height, weight and BMI. Furthermore, no significant difference was found for years of weightlifting experience, the best weightlifted at the last competition as well as for all kinematic variables ($P > .05$).

A mixed-design 3 × 3 (group × time) ANOVA (Table 3) with repeated measure on the second factor revealed a significant main effect of time for Dx2 ($P < .001$, $\eta^2 = .30$) and DxT ($P = .003$, $\eta^2 = .17$); a significant main effect of group-by-time interaction for Dx2 ($P < .001$, $\eta^2 = .29$); DxL ($P < .001$, $\eta^2 = .43$); VTR ($P < .001$, $\eta^2 = .30$) and Diff_Max_Vvel ($P < .001$, $\eta^2 = .29$). Post hoc analysis of the group-by-time interaction effect showed that in the MAE group, the Dx2, DxL and Diff_Max_Vvel values were significantly lower at T_1 than T_0 ($P = .005–<.001$) as well as at T_2 versus T_0 ($P = .003–<.001$); in the MAE group, the VTR values were also significantly decreased at T_1 versus T_0 ($P = .004$). No significant differences were found between T_1 and T_2 in the MAE group. In the DI group, the Dx2 values decreased at T_1 versus T_0 as well as T_2 versus T_1, however a statistical significance was found only at T_2 versus T_0 ($P = .002$). In the DI group, the Diff_Max_Vvel values were significantly increased at T_2 versus T_0 ($P = .018$). In

Table 3. Kinematic parameters analysed. Data are reported as mean (standard deviation).

Kinematic variables	MAE			DI			C			ANOVA		
	T_0	T_1	T_2	T_0	T_1	T_2	T_0	T_1	T_2	Time x group (p)	Time (p)	Group (p)
Dx2 (cm)	10.38 (2.54)	7.94 (2.41)	8.56 (1.83)	10.27 (3.27)	9.98 (3.64)	9.21 (3.22)	10.07 (1.02)	9.81 (1.04)	9.98 (0.88)	<.001	<.001	–
DxV (cm)	7.64 (2.53)	6.74 (2.32)	7.27 (2.23)	7.50 (1.09)	7.45 (1.07)	7.74 (1.62)	7.56 (2.12)	7.77 (1.90)	7.93 (1.81)	–	–	–
DxT (cm)	14.53 (5.34)	12.36 (4.99)	12.78 (5.89)	13.92 (6.10)	13.83 (5.05)	13.88 (4.34)	14.20 (0.97)	15.21 (1.32)	15.57 (2.57)	–	.030	–
DxL (cm)	14.53 (2.49)	12.36 (3.17)	12.78 (3.09)	13.92 (4.08)	13.82 (3.03)	13.88 (2.82)	14.20 (1.50)	15.21 (2.76)	15.57 (2.13)	<.001	–	–
VTR (cm)	23.57 (5.18)	22.40 (5.03)	22.35 (5.18)	23.20 (3.14)	23.05 (2.31)	23.54 (5.14)	23.90 (4.47)	25.68 (4.27)	25.61 (3.89)	<.001	–	–
Vvel_FP (m/s)	1.22 (0.23)	1.30 (0.22)	1.24 (0.26)	1.24 (0.20)	1.21 (0.18)	1.24 (0.15)	1.26 (0.08)	1.26 (0.10)	1.25 (0.09)	–	–	–
Max_Vvel (m/s)	2.01 (0.09)	2.03 (0.08)	2.03 (0.08)	2.00 (0.10)	2.00 (0.11)	2.03 (0.15)	2.02 (0.07)	2.00 (0.07)	2.02 (0.06)	–	–	–
Diff_Max_Vvel (m/s)	0.12 (0.05)	0.09 (0.04)	0.09 (0.04)	0.11 (0.05)	0.12 (0.07)	0.13 (0.07)	0.13 (0.05)	0.12 (0.05)	0.12 (0.04)	<.001	–	–

MAE: method of amplification of error; DI: direct instruction; C: control; Dx2: The horizontal displacement from the start position to the start of the second pull; DxV: The horizontal displacement from the second pull position to the forward position; DxT: The horizontal displacement from the start position to the catch position; DxL: The horizontal displacement from the most forward position to the catch position; VTR: The vertical displacement from the maximum height to the catch position; Vvel_FP: The maximal vertical linear velocity of the barbell during the first pull; Max_Vvel: The maximal vertical linear velocity of the barbell; Diff_Max_Vvel: The difference between the right and left sides of the barbell's maximal vertical linear velocity.
P values adjusted for multiple testing by the Holm–Bonferroni method.

the DI group, no significant differences were found for other kinematic variables. In the C group, the VTR values were significantly greater at T_1 than T_0 ($P < .001$), as well as at T_2 than T_0 ($P = .005$). Moreover, the DxL values were significantly increased at T_2 versus T_0 ($P = .002$).

No significant differences were found between groups after the training intervention (T_1) nor at the retention test (T_2) for all the kinematic parameters.

For all significant effects of time and group-by-time interaction, the effect size (η^2) was >.16, showing a medium to large effect. Post hoc power analyses revealed that there was an 83–99% chance of detecting a medium to large effect size ($\eta^2 = 16$–43) significant at the .05 level (two-tailed). This shows that our sample size of 30 was adequate and the study was sufficiently powered to assess the statistical significance of the changes over time for the more representative kinematic variables of the lift. Power analysis with power ($1 - \beta$) set at the recommended 0.80 level and $\alpha = .05$ (two-tailed) indicated the sample size would have been approximately 261 subjects to detect a small effect size.

Discussion

The aim of this study was to test the efficacy of a learning strategy called MAE in weightlifting and to compare the relative effectiveness of MAE with traditional DI and with a no-feedback control condition. After only one practice session, findings provided evidence for the assumption that the MAE may be more beneficial to performance, in terms of the barbell trajectory pattern, than DI; this benefit remained present in the retention test.

The results showing the differences between groups for all the kinematic variables in both T_1 and T_2 are probably non-significant due to a small sample size. Moreover, despite the MAE group showing benefits from error amplification more than the verbal instruction of the DI group, one training session alone might not be enough to reveal a statistical difference between these two types of instruction.

As noted in the results section, the MAE group showed a greater decrease at T_1 and T_2 in several horizontal displacement parameters. Statistical analysis showed significant decreases at T_1 and T_2 for Dx2 in the MAE group (-23.54% and -17.56%, respectively), whereas in the DI group, this occurred only at T_2 (-10.32%). It should be noted that these results were in line with the coach's qualitative analysis, reporting that the MAE group showed a greater reduction of the "selected error" than the other two groups. In regard to the DI group, the coach observed a greater reduction of the "selected errors" at T_2 than at T_1. However, with time practice involving DI may be expected to produce some improvement. Another possible reason for this improvement might be the effect of focus of attention. During the post-training session, the automatic control process is likely to be disrupted by the DI intervention, causing reduced performance. However, in the retention test, without feedback, the automatic control process takes priority. Feedback may also be assimilated more slowly through DI as the process involves conscious reasoning, the effects of which may appear after a longer period of time. Indeed, as mentioned previously, studies provide converging evidence that focus of attention on the movement effects is more effective than a focus on the movements themselves (Wulf et al., 1998).

Moreover, the results demonstrate that the MAE group improved performance at T_1 and T_2 in the total amount of horizontal displacement from the beginning of the lift to the catch position (DxT: -12.71% and -14.30%, respectively), and from the most forward position to the catch position (DxL: -14.92% and -12.03%, respectively). Regarding the vertical displacement from the maximum height to the catch position (VTR), the MAE group showed a greater decrease than the other two groups. Minimisation of the barbell's vertical drop from maximum height achieved to the catch position is considered one of the most important indicators of an effective technique (Gourgoulis et al., 2000; Isaka et al., 1996). The MAE group also showed an improvement in the vertical linear velocity of the barbell at the first

pull and the maximal vertical linear velocity of the barbell. Thus, for good barbell trajectory kinematics, errors in the starting position or at the first pull need particular attention. These results are supported by the findings of previous studies (Akkus, 2012; Campos et al., 2006; Winchester et al., 2009), which found significant correlations between biomechanical variables in successful attempts in competitive weightlifting.

In the present study, it is interesting to note that a change in the overall bar path reduced the differences in the maximal vertical velocity between the right and left sides of the barbell. In fact the MAE group showed a significant decrease in this asymmetry at T_1 and T_2 (−23.05% and −25.02%, respectively), whereas the DI group revealed an increase in the asymmetry in both T_1 and T_2 (15.62% and 22.96%, respectively).

The findings suggest that the MAE is an effective strategy for correcting the pattern of motion in a short time. The amplified error trial provides the learner with new intrinsic feedback, stimulates the functions of perceptive categorisation and the conceptual and symbolic elaboration of the received information and consequently enhances the athlete's natural error detection capability.

Studies using functional magnetic resonance imaging suggested that the cingulate motor area in particular is involved in error detection (Carteer et al., 1998; Kiehl, Liddle, & Hopfinger, 2000). It is implicit in error detection that the internal monitoring system is able to make a comparison, and previous studies suggest that this comparison may involve representations of the current action and the correct action (Bernstein, Scheffers, & Coles, 1995). In MAE strategy, the mental comparison process between the subject's exaggerated movement (constrained trial) and the subject's usual movement would be expected to yield a signal and the amplitude of this signal depends on the degree to which the two representations differ. In turn, when the response that follows is correct (i.e., during "free trial"), this representation is used by the internal comparison process to generate a "mismatch" with his original pattern. The degree of this "mismatch" would depend on the differences between the pair of representations (Bernstein et al., 1995). In this way, the amplified trial allows the learner to better understand what is not to be done, thereby enhancing the correction of the motor error (Milanese et al., 2008, in press). In contrast, DI through descriptive and prescriptive feedback informs the learner of his mistake in relation to the task criterion; however, it does not allow the learner to explore the extremities of the movement space to arrive at the task-relevant solution (Newell, 1991).

To our knowledge, this is one of the first studies to take qualitative observation of error correction and quantitative measurement of improved performance to demonstrate the effectiveness of the training intervention and also to compare the relative effectiveness of the MAE against DI in a complex skill such as weightlifting. However, there were several limitations to the current study. First, due to the small sample size (n = 10 participants for each group), caution should be taken with regards to the generalisation of the results (e.g., different ability levels and other sport skills). Second, although we think that horizontal displacement of the barbell is an accurate and valid measurable variable available to us for weightlifting

performance, kinetic parameters such as ground reaction force and power should be assessed in order to measure the finer intricacies of improved performance. Third, the errors were identified through qualitative analysis of the coach and they were not measured. The improvement was measured indirectly with the kinematic parameters that are considered good predictors of weightlifting performance. It should be noted that years of coaching experience leads not only to the identification of errors but also to their prioritisation according to the effects on the final outcome and on the biomechanics of the movement. Even though this study only examined kinematic parameters related to the snatch technique as a function of an error correction strategy, not learning itself, the authors argue that error amplification might facilitate motor learning, as MAE addresses the error from the personal perspective of the individual to help the athlete build an efficient individual technical pattern. In following with non-linear pedagogy (Chow et al., 2006), skill is a reflection of a personal dynamic exploratory activity, not the stereotypical reproduction of a static representation of action. This conceptualisation is a good example of the important role of functional variability in achieving successful performance in sport. Variability in movement plays a functional role in helping individuals adapt to constraints which vary according to environmental, anatomical and physiological changes due to performance or disease (Davids, Glazier, Araujo, & Bartlett, 2003). The MAE implements this theory insofar it allows the learner to search for a task solution within their own individual constraints.

Further research will also be necessary to evaluate the persistence of the effects of MAE instruction over time and under psychologically stressful conditions. We still need to explore the impact of MAE on the learning of other sport tasks in novice and elite athletes to confirm its continued success. Another extremely important field of research would be adapted physical activity, where it is important to develop and evaluate efficient therapeutic interventions aimed at improving balance and coordination skills. For example, to help a person with lower-limb amputation relearn balance skills and weight transfer.

The results with the MAE strategy may greatly influence the methods of coaching and teaching of movement in the future and it may also be considered for research in different fields such as sport psychology, physical therapy, physical education, music instrument teaching and other forms of motor skill training. However, this will only be possible by continuing to bridge the gap between qualitative and quantitative data collection and analysis.

Acknowledgements

Disclosure statement

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