Real-time feedback to reduce low-back load in lifting and lowering

Punt, Michiel; Nematimoez, Mehdi; van Dieën, Jaap H; Kingma, Idsart

published in
Journal of Biomechanics
2020

DOI (link to publisher)
10.1016/j.jbiomech.2019.109513

document version
Version created as part of publication process; publisher's layout; not normally made publicly available

Journal of Biomechanics xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Real-time feedback to reduce low-back load in lifting and lowering

Michiel Punt [a,b,*], Mehdi Nematimoez [a,c], Jaap H. van Dieën [a], Idsart Kingma [a]

[a] Department of Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam Movement Sciences, Amsterdam, the Netherlands
[b] Research Group Lifestyle and Health, Utrecht University of Applied Sciences, Utrecht, the Netherlands
[c] Department of Sport Biomechanics, Faculty of Physical Education and Sport Science, Kharazmi University, Tehran, Iran

ARTICLE INFO

Article history:
Accepted 11 November 2019
Available online xxxx

Keywords:
Real-time feedback
Low back pain
Moment
Reinforcement learning
Trunk inclination

ABSTRACT

Low-back pain (LBP) is a common health problem. Literature indicates an exposure-response relation between work-related lifting and LBP. Therefore, this study investigated effects of three kinds of real-time feedback on low-back load, quantified as lumbar moments, during lifting. We recruited 97 healthy male and female participants without a recent history of LBP and without prior biomechanical knowledge on lifting. Participants were assigned to groups based on the time of enrollment, filling the four groups in the following order: moment feedback, trunk inclination angle feedback, lumbar flexion feedback, and a control group not receiving feedback. Feedback was given by a sound when a threshold level of the input variable was exceeded. Participants were unaware of the input variable for the feedback, but were instructed to try to avoid the audio feedback by changing their lifting strategy. The groups with feedback were able to reduce the audio feedback and thus changed the input variable towards a more desired level. Lumbar moments significantly decreased over trials in the inclination and moment feedback groups, remained similar in the lumbar flexion group and increased in the control group. Between group comparisons revealed that low-back load was significantly lower in the moment and inclination groups compared to the control group. Additionally, moments were lower in the inclination group than in the lumbar flexion group. Real-time feedback on moments or trunk inclination is a promising tool to reduce low-back load during lifting and lowering.

1. Introduction

Low-back pain (LBP) is a very common health problem (Hoy et al., 2010), which negatively affects quality of life (Kovacs et al., 2004) and is the leading cause of absence from work (Balagué et al., 2012). Despite the fact that most LBP is non-specific and thus has no identified pathophysiological source, a variety of factors have been established as potential causes of LBP (Balagué et al., 2012). One frequently mentioned cause is work-related lifting, for which an exposure-response relationship of intensity and duration of lifting with LBP has been established (Bergmann et al., 2017; Coenen et al., 2014).

Numerous studies have attempted to develop effective preventive interventions, but according to a recent review, the effectiveness of such interventions is very limited (Schaafsma et al., 2015). More specifically, also evidence on effects of ergonomic interventions and assistive devices aiming to reduce exposure remains inconclusive (Ammendolia et al., 2005; Sahar et al., 2008; van Duijvenbode et al., 2007).

A novel, more targeted approach is a direct focus on the exposure to low-back loading (Bergmann et al., 2017; Coenen et al., 2014) (Bergmann et al., 2017; Coenen et al., 2014) (Bergmann et al., 2017; Coenen et al., 2014). Modern technologies like inertial measurement units (IMU) and force insoles may provide the opportunity to reliably monitor low-back load during daily-life lifting tasks (Faber et al., 2018). Such a system could also provide real-time feedback on low-back load during lifting tasks. Three studies have explored the potential of giving real-time feedback to reduce low-back load (Agruss et al., 2004; Kernozek et al., 2006; Lavender et al., 2007). Agruss et al. used EMG signals from the trunk muscles as the source for feedback, while Kernozek et al. and Lavender et al. provided feedback on the magnitude of the lumbosacral (L5S1) joint moment. Both studies reported promising results with respect to reduction of low-back load.

Real-time feedback can act as an external cue for reinforcement learning in humans. The feedback, for instance a sound, can act as a negative reinforcement which will challenge individuals to adapt their lifting strategy, while the absence of the sound acts as a positive reinforcement. To sort an effect, the variable which triggers the feedback needs to contain relevant information on low-back load. To this end several variables are worth exploring. First, feed-

* Corresponding author at: Heidelberglaan 7, 3584 CS Utrecht, the Netherlands.
E-mail address: michiel.punt@hu.nl (M. Punt).

https://doi.org/10.1016/j.jbiomech.2019.109513
0021-9290/

back about the L5S1 moment itself (Kernozek et al., 2006; Lavender et al., 2007) and second kinematic variables trunk inclination and lumbar flexion. A reduction of these easily measurable kinematic variables will shorten the moment arm of the trunk and consequently reduce the moment. We did not consider erector spine surface electromyography (EMG) as applied by (Agruss et al., 2004). Acquiring EMG data is practically challenging and the feedback will not be valid in situation which require substantial flexion due to the flexion-relaxation phenomenon (Dickey et al., 2003).

It is currently largely unknown to what extent real-time feedback in lifting and lowering tasks can reduce low-back load, whether a potential effect is retained and which feedback variable is most effective in reducing low-back load during lifting tasks. Therefore, the objective of this study was to examine to what extent real-time feedback reduces low-back load in lifting and which feedback variable (L5S1 net moment, trunk inclination and lumbar flexion) is most effective in doing so.

2. Method

2.1. Participants

As changes across trials were expected to be more variable in the feedback groups than in the control group, we included a minimum of 20 participants in the feedback groups, but limited the control group. A total of 97 male and female participants without a recent history of low back pain volunteered. The study was approved by the local ethical committee and all participants gave written informed consent. Participants had no knowledge about the biomechanics of lifting nor had they participated in any other studies related to lifting and biomechanics. Participants were assigned to one of four groups in order of enrollment, first recruited participants in the moment (L5S1 moment) feedback group, next participants in the trunk inclination (sagittal plane trunk angle relative to the vertical) group, next participants in the lumbar flexion feedback sagittal plane angle between trunk and pelvis) feedback group, and the final participants to the control group not receiving feedback.

2.2. Experimental design and procedure

We created a mock-up environment to simulate daily-life lifting tasks. To assess generalization of feedback effects, variations over lifts were obtained by predefining lifting and lowering locations distributed over three horizontal (left/center/right) positions and two depth (far/nearby) positions. The neighboring positions were 10 cm apart, thus participants needed to perform minor side steps to align with the box. The handles of the box were at a height of 26.5 cm. Participants were not allowed to make substantial longitudinal rotations during the lifting tasks as the markers would move out of the field of view.

All four groups performed 4 trials wherein each trial consisted of 12 lifting and 12 lowering tasks with a box of 10 kg. In between trials, a 3 to 5 min break was given. Trial 1 served as a reference trial to obtain a participant specific threshold value for the feedback. For each of the feedback modes, threshold selection was based on variations normally obtained across instructed lifting techniques (Kingma et al., 2010, 2006) and on pilot work. The threshold value for the moment feedback group derived from trial 1 was set at 80% of the average of the observed 24 peak sagittal plane moments (12 times lifting and 12 times lowering), see for a detailed description of the calculations further down the methods section. Exceeding this threshold value resulted in a sound being played by the computer. Similarly, thresholds were set at 80% of the average of the observed peak trunk inclination angles and 70% of the average of the observed peak lumbar flexion angles during trial 1.

Trials 2 and 3 served as the intervention trials wherein feedback was given (except for the control group) and trial 4 served as a retention test. Prior to trial 2, participants were instructed that they should try to avoid the sound by changing the way they lifted and lowered the box. However, they were not allowed to lift with one hand only, or to step off the force plate. We decided to not explain what kind of information triggered the sound, as explaining the feedback would guide participants towards a solution to reduce the variable that was fed back, while the aim of the study was to solely study the effect of real-time feedback on back moments. Prior to trial 4, participants were instructed that they would no longer hear the sound, but that they should try to apply the same lift and lowering strategy as learned during the intervention trials.

Anthropometric measures were taken from the foot, shank, thigh, pelvis, and thorax to estimate mass, centre of gravity and inertia per segment. Kinematic data were obtained, using three camera arrays of a 3D movement registration system (Optotrak Certus system; Norton Digital Inc.), at a sample rate of 50 Hz. Light emitting diodes (LED) markers were attached to both shanks and thighs, pelvis at the sacrum and thorax at the T6 spinous process to capture kinematics. The markers were related to anatomical landmarks by a calibration procedure (Kingma et al., 1996). Ground reaction forces were collected with a custom-made 1.0 × 1 .0 m force plate at a sample rate of 200 Hz, these plates show excellent linearity and Center of Pressure errors < 4 mm (Kingma et al., 2004). To estimate net moments at the lumbosacral joint (L5S1) a bottom-up 3-D linked segment model was used (Faber et al., 2011; Hof, 1992; Kingma et al., 1996). During offline analysis, marker data and force plate data were low-pass filtered using a bi-directional Butterworth filter with a cut-off frequency of 5 Hz, subsequently the same linked segment model was used to estimate net moments at the L5S1 joint in the sagittal plane.

Online data analysis using a custom-made Matlab (2017B) program allowed us to provide real-time feedback on the three feedback variables (L5S1 moment, lumbar flexion and trunk inclination). The program integrated the participant specific calibration procedure and received kinematic and force plate data at 25 Hz. In pilot data, the online (low sample rate and without filtering) L5S1 moments estimates closely resembled offline (normal sample rate with filtering) estimates ($R = 0.98$ and root mean square error = 2.3Nm) without structural over- or under estimation.

Primary outcome variables to quantify low-back load were the L5S1 peak moment in the sagittal plane and time above the L5S1 moment threshold value (TaMT) in the sagittal plane. Kinematic variables to characterize the lifting strategy were obtained at the time of the peak moment. These variables were: 1) trunk inclination in the sagittal-plane, 2) lumbar flexion, the angle between the trunk and the sacrum in the sagittal-plane 3) knee angles in the sagittal-plane, and 4) the maximum upwards trunk velocity when lifting the box and the maximum downwards trunk velocity when lowering the box. Note that peak vertical velocity was reached prior to peak moment in case of lowering and after peak moment in case of lifting.

For the feedback groups, the time above the set threshold (TaT) was determined as well to examine if and to what extent participants were able to adapt their lifting strategy to avoid the audio feedback.

2.3. Statistical analysis

Normal distribution of the data was tested using the Kolmogorov-Smirnov test. Sphericity was tested using Mauchly's

Please cite this article as: M. Punt, M. Nematimoez, J. H. van Dieën et al., Real-time feedback to reduce low-back load in lifting and lowering, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2019.109513

test, and if significant a Greenhouse-Geisser correction was used. For each group, mean and standard deviation for demographic characteristics like body weight and height, and age are reported. We compared demographic characteristics between the four groups (control, inclination feedback, lumbar flexion feedback and moment feedback) using ANOVAs. When these tests revealed a significant difference, the variable concerned was used as a covariate in further analyses. Before conducting statistical analyses, we averaged over box horizontal positions (left/center/right). Subsequently, we examined the effects of the following four factors: box position (two levels, nearby and far), lifting task (two levels, lifting and lowering) and trial (four levels), as follows.

2.3.1. Reducing feedback time

First, we examined whether participants were able to reduce the time that feedback was provided by changing their lifting strategy. To this end, we determined the time above the set threshold value (TaT) for each feedback group. The effect of feedback was examined per group using a repeated measures ANOVA considering all other factors (trial, box position and lifting task), but only the feedback factor was interpreted, as detailed below.

2.3.2. Effect of feedback over trials

Next, the effect of feedback on low-back load was examined, expressed by the dependent variables: peak moment at L5S1 and TaMT. Furthermore, the effects of feedback on lifting and lowering strategy were examined using the kinematic variables: knee angle, lumbar flexion, trunk inclination and vertical peak velocity. We used repeated measures ANOVAs with group (4 groups) as between-subjects factor and trial, box position and lifting task as within-subject factors. Additionally, to clarify results and reduce data dimensionality, if no significant 3-way or 4-way interactions with trial, box location, lifting task and group were found, we concluded that the effect of feedback was similar among locations and lifting tasks to average over these conditions. In case main effects of trial and/or an interactions between trial and group were found, specific follow-up analyses were performed. Follow-up testing was performed using 1-way repeated ANOVAs per group per variable, to examine the main effects of trial. If a significant main effect was found, Bonferroni-corrected post-hoc testing was performed to examine if subsequent trials differed from trial 1.

2.3.3. Between-group differences at trial 4

Finally, we examined between feedback group differences at trial 4. As groups differed at baseline trial 1, we corrected these differences by first normalizing data to values obtained in trial 1. A one-way ANOVA per dependent variable was conducted. In case of a significant main effect of group, further Bonferroni-corrected post-hoc testing was performed to examine which feedback groups differed from each other.

For the main findings and interactions partial eta squared effect sizes are reported to quantify the size of the effects. Effect sizes of roughly 0.01 are considered small, 0.06 are considered medium and >0.14 are considered large. All statistical analyses were performed in SPSS version 25.0 and a p-value of $\leq$0.05 was considered statistically significant.

3. Results

From the 97 participants, we excluded 5 participants due to missing markers or mal-functioning of instrumentation during the measurement. The remaining 92 participants are described in Table 1. One-way ANOVAs revealed no significant differences between the four groups with respect to demographic characteristics (Table 1).

3.1. Reducing feedback time

Participants were reduced TaT over trials in each of the feedback groups (Fig. 1; $p < .001$), indicating that participants changed their lifting strategy in line with the feedback provided.

3.2. Effect of feedback over trials

No 3-way or 4-way interactions with trial and feedback group were found (Table 2), thus the effect of feedback was similar among near and far, and among lifting and lowering. Therefore, in subsequent statistics and in the figures, results have been averaged over box positions and lifting tasks.

Two-way interactions of trial and feedback were significant and follow-up analyses were performed poer group. Brackets in Fig. 2 indicate Bonferroni-corrected post hoc differences between trials within a specific feedback group. Peak moments significantly decreased over trials in the moment feedback group (to 91% at trial 4) and the inclination feedback group (to 88.3% at trial 4) (Table 3, Fig. 2). Peak moments significantly increased over trials in the control group (to 106.1% at trial 4) and no changes were observed in the lumbar flexion group. TaMT significantly (Table 3, Fig. 2) decreased in all three feedback groups, moment group (−0.24 s at trial 4), inclination group (-0.26 s at trial 4) and lumbar flexion group (−0.1 s at trial 4).

Brackets in Fig. 3 indicate Bonferroni-corrected post hoc differences between trials within a specific feedback group for a specific kinematic variable. Trunk inclination decreased significantly (Table 3, Fig. 3) in all three feedback groups, moment (−20° at trial 4), inclination (−25° at trial 4) and lumbar flexion (−19° at trial 4). Lumbar flexion angles significantly decreased (Table 3, Fig. 3) in all feedback groups (moment (−14° at trial 4), inclination (−19° at trial 4) and lumbar flexion (−16° at trial 4)) and in the control group (−4° at trial 4). Knee angles significantly increased (Table 3, Fig. 3) in the moment (28° at trial 4), inclination (34° at trial 4) and lumbar flexion feedback groups (26° at trial 4) and in the control group (9° at trial 4). No main effects of trial, nor interactions of trial and group on vertical trunk velocity were found (Fig. 3; Table 2).

3.3. Between-group differences in trial 4

Peak moment reductions in trial 4 were significantly larger for the moment and inclination feedback groups as compared to the control group. Moreover, peak moments in trial 4 for the inclination feedback group were significantly lower as compared to the lumbar flexion group (Table 4 Fig. 2). The change in TaMT was significantly larger in the inclination group compared to the control group (Table 4, Fig. 2).

With regards to kinematic variables, trunk inclination (Table 4, Fig. 3) was significantly more reduced in the feedback groups than in the control group in trial 4. Lumbar flexion angle was significantly more reduced in all feedback groups as compared to the control group (Table 4, Fig. 3). Finally, the change in knee angle was significantly larger for the trunk inclination feedback group as compared to the other groups (Table 4, Fig. 3).

4. Discussion

The objectives of this study were to examine to what extent real-time feedback reduces low-back load in lifting and which feedback variable (L5S1 moment, trunk inclination and lumbar flexion) is most effective in doing so and whether effects are retained after feedback is stopped. First, participants were able to address the unknown feedback source. They explored how to change the lifting strategy and learned to reduce the time that

Table 1
Demographic characteristics for all four groups and results for between group comparison ANOVA.

	N = 14 Control group	N = 29 Moment group	N = 28 Inclination group	N = 21 Lumbar flexion group	Between group effect	
Variable	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F	P
Female/male	7 / 7	7 / 22	15 / 13	7 / 15		
Age (years)	23.7 ± 8	25.7 ± 4	24.9 ± 7	25.9 ± 10	0.32	0.81
Height (m)	1.77 ± 0.1	1.77 ± 0.09	1.79 ± 0.09	1.78 ± 0.09	0.12	0.94
Weight (kg)	73.5 ± 10	72 ± 11	72.4 ± 10	72 ± 12	0.07	0.97
BMI (kg/m2)	23.4 ± 3.2	22.7 ± 2.5	22.6 ± 2.5	22.6 ± 2.7	0.35	0.79

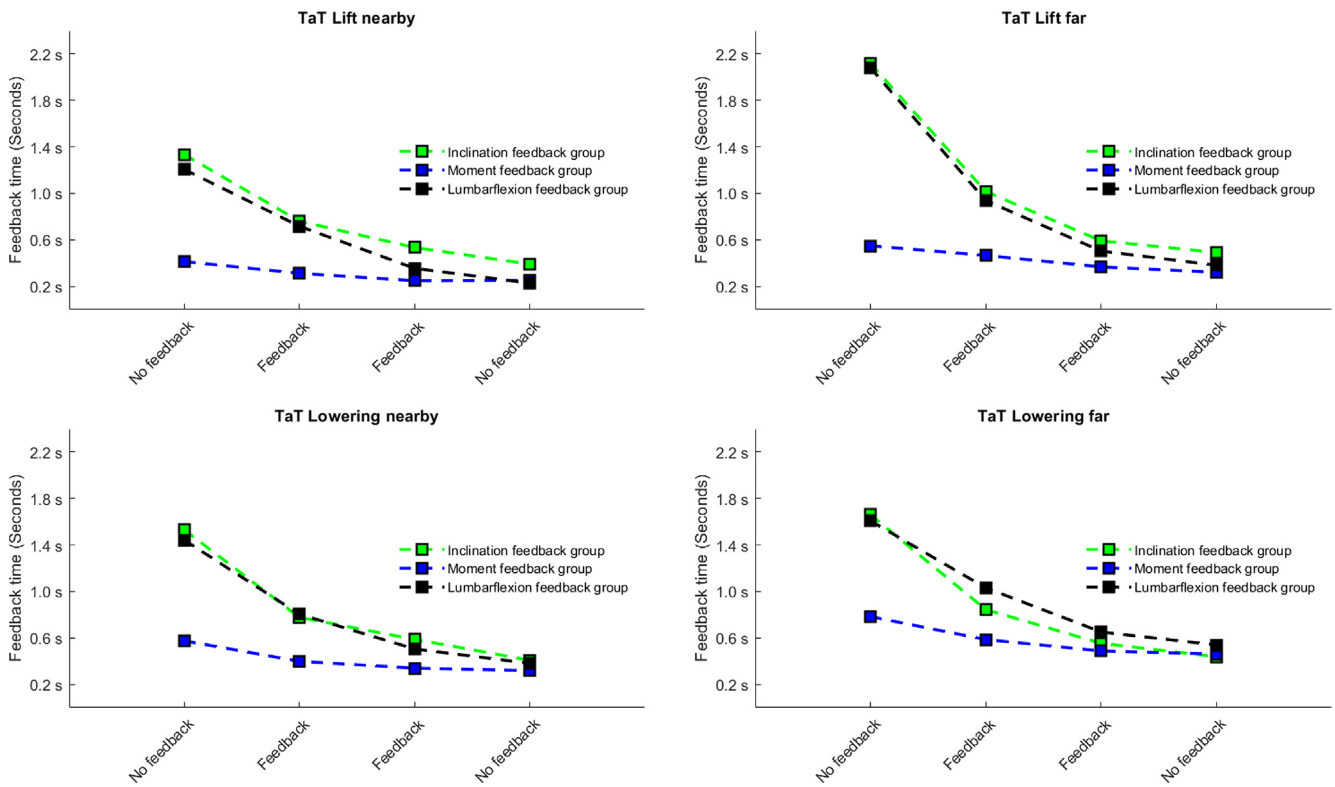

Fig. 1. The time receiving feedback for a given condition despite of which trial was performed; lifting's are the upper panels, lowering are the lower panels, nearby lifts are the left panels, far lifts are the right panels. The three different lines are three different feedback groups, namely, green inclination feedback, blue is the moment feedback group and black is the lumbar flexion group. The control group is not reported due to the absence of feedback. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Results of the Within – between group repeated measures (M)ANOVA for the effects of trial, group, location and lifting task) on low back loading and kinematic variables.

	4-Way Interaction Effect		3-Way Interaction Effect				2-Way Interaction Effect		Main effect						
	Trial * Group * Location * Lift		Trial * Group * Location		Trial * Group * Lift		Trial * Group			Trial			Group		
Variable	F	P	F	P	F	P	F	P	η^2	F	P	η^2	F	P	η^2
Peak moment	0.6	0.79	1.1	0.39	1.2	0.29	**5.7**	**<0.01**	**0.16**	**6.1**	**0.01**	**0.06**	0.7	0.50	
TaT moment	1.4	0.18	1	0.44	1.1	0.34	**3.2**	**<0.01**	**0.10**	**28.1**	**<0.01**	**0.24**	**5.5**	**<0.01**	**0.15**
Knee angle	1	0.43	1.8	0.06	0.8	0.58	**5.6**	**<0.01**	**0.08**	**87.3**	**<0.01**	**0.41**	2.6	0.06	
Trunk inclination	0.4	0.89	0.9	0.47	0.7	0.64	**4.4**	**<0.01**	**0.13**	**87**	**<0.01**	**0.49**	**5.2**	**<0.01**	**0.15**
Lumbar flexion	0.7	0.67	0.5	0.79	1.3	0.27	**2.5**	**0.03**	**0.16**	**62.9**	**<0.01**	**0.49**	2.2	0.09	
Trunk vert. velocity	1	0.38	0.5	0.67	2.2	0.05	1.1	0.34		0.1	0.78		0.6	0.61	

Results are Greenhouse Geisser corrected p-values.
P-values < .05 are printed in bold.

Please cite this article as: M. Punt, M. Nematimoez, J. H. van Dieën et al., Real-time feedback to reduce low-back load in lifting and lowering, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2019.109513

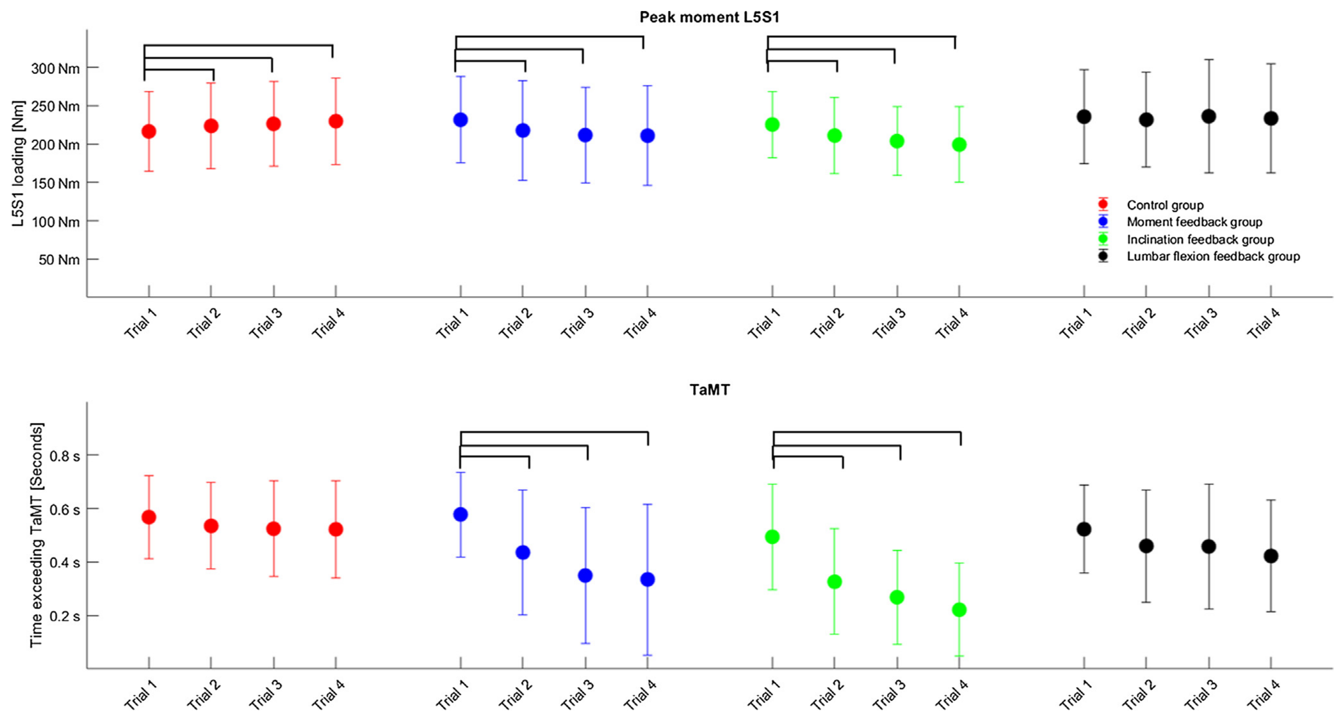

Fig. 2. Primary loading value variables. Upper panel, average L5S1 peak moment per trial for the four groups. Lower panel, time exceeding the moment threshold value for the four groups. The different colors represent the four experimental groups. The brackets indicate Bonferroni-corrected significant post-hoc differences per group.

Table 3
Results of a one-way repeated measures ANOVA, testing the effect of feedback over the four trials per dependent variable per feedback group.

	Feedback type											
	Control			Moment			Inclination			Lumbar flexion		
Variable	F	P	η^2	F	P	η^2	F	P	η^2	F	P	η^2
Peak moment	**5.1**	**<0.01**	**0.28**	**8.6**	**<0.01**	**0.24**	**21.7**	**<0.01**	**0.44**	0.33	0.69	
TaT moment	1.8	0.19		**17.5**	**<0.01**	**0.39**	**27.8**	**<0.01**	**0.50**	**1.79**	**<0.01**	**0.08**
Knee angle	**6.2**	**0.01**	**0.32**	**22.0**	**<0.01**	**0.45**	**54.4**	**<0.01**	**0.66**	**12.3**	**<0.01**	**0.38**
Trunk inclination	2.7	0.11		**24.5**	**<0.01**	**0.50**	**65.7**	**<0.01**	**0.74**	**28.9**	**<0.01**	**0.52**
Lumbar flexion	**4.2**	**0.04**	**0.17**	**27.5**	**<0.01**	**0.47**	**80.4**	**<0.01**	**0.71**	**21.9**	**<0.01**	**0.59**

P-values < .05 are printed in bold.

feedback was given or even to avoid feedback entirely. Subsequently, our results indicate that real-time feedback controlled by either moment or trunk inclination resulted in a substantial reduction in peak moments and the time exceeding the threshold value for L5S1 moments (TaMT) as indicated by the observed large effect sizes (Table 3). In contrast, real-time feedback of lumbar flexion did not result in reduced peak moments and only a minor decrease (small effect size) in TaMT was observed. Interestingly, in the control group we observed a small significant increase in peak moment, increase in knee flexion and lumbar flexion. It is unlikely that it is due to fatigue, as fatigue would probably result in reduced knee flexion (van Dieën et al., 2001) and has been shown to have negligible effects on back loading(van Dieën et al., 1998). Therefore, we conclude that the participants apparently adapted their lifting technique, which was clearly not beneficial for lower back loading as it coincided with increased peak moments. Our findings are in agreement with previous studies exploring real-time feedback to reduce low-back load (Agruss et al., 2004; Kernozek et al., 2006; Lavender et al., 2007). Despite differences in methodology, all studies found similar effects of feedback on low back loading. Our observed changes in low-back load coincided with substantial changes in lifting strategy: trunk inclination and lumbar flexion decreased over trials, and as a compensation to still reach the box, knee angles increased over trials in all three feedback groups, while this was less so in the control group. Participants in the moment feedback group tended, in contrast to the other groups, to reduce lifting and lowering speed (Fig. 3), but the interaction of group and trial was not significant for lifting speed. Finally, our results do not show a relation between already performing well in terms of for instance a limited trunk inclination or moment in trial 1 and the ability to benefit from the real-time feedback. We think this is mainly due to the use a of a relative and personalized threshold values.

From a practical perspective and for a future study in a daily-life setting, trunk inclination as a feedback variable may have the highest potential, as trunk inclination outperformed lumbar flexion in terms of reducing low-back load and was similarly effective as moment feedback. Trunk inclination is easily measurable in daily life using a single inertial measurement unit, while measuring moments at L5S1 is challenging and requires more instrumentation (Faber et al., 2018).

This study has several limitations, which should be taken into account for future work in this area. An interesting finding was the robustness of the effect of feedback to the different conditions. The effect of feedback yielded similar results for lifting and lowering as well as for locations nearby and far (Table 2). This is an

Please cite this article as: M. Punt, M. Nematimoez, J. H. van Dieën et al., Real-time feedback to reduce low-back load in lifting and lowering, Journal of Biomechanics, https://doi.org/10.1016/j.jbiomech.2019.109513

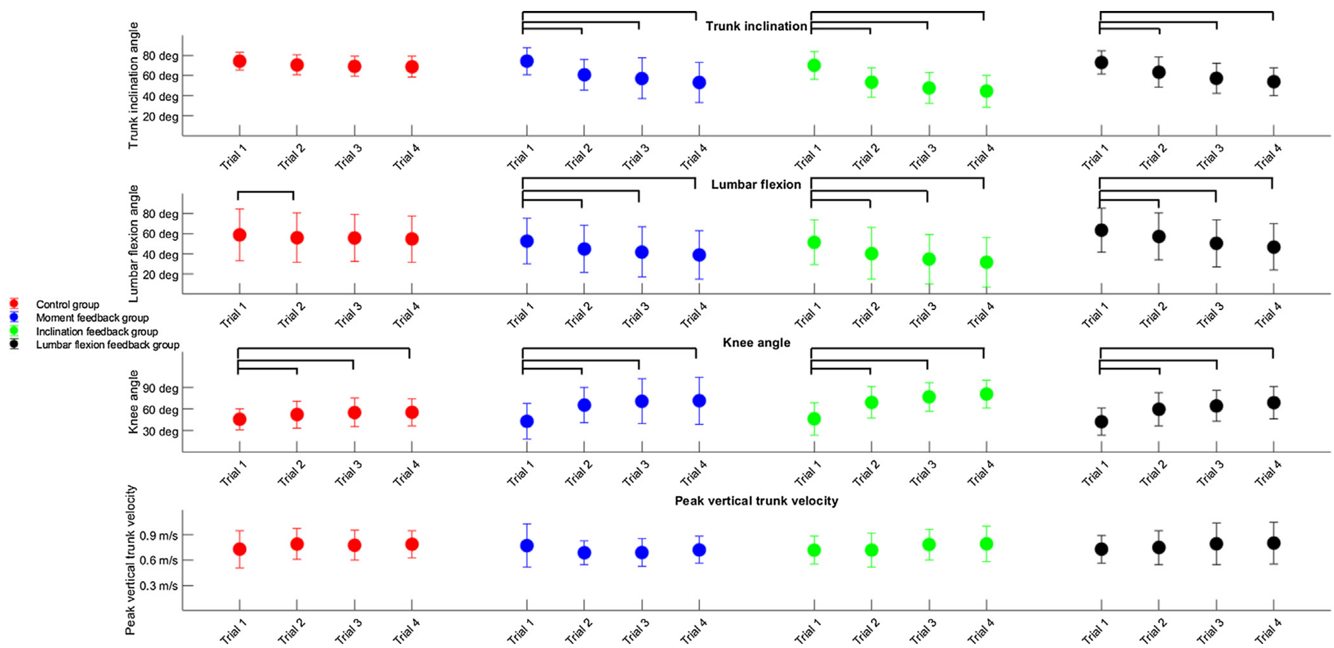

Fig. 3. Kinematic lifting and lowering variables for trunk inclination, lumbar flexion, knee angle and peak vertical velocity of the trunk averaged over lifting and lowering conditions per trial and for all four experimental groups. The brackets indicate significant post hoc differences per group between certain trials for the dependent variable.

Table 4
Results for the one-way between group ANOVA on changes in trial 4 relative to trial 1, testing low back loading and kinematic variables.

	Between group effect	
Variable	F	P
Peak moment (Trial 4)	**8.1**	**<0.01**
TaT moment (Trial 4)	**4.3**	**<0.01**
Knee angle (Trial 4)	**3.2**	**0.02**
Trunk inclination (Trial 4)	6.5	**<0.01**
Lumbar flexion (Trial 4)	**8.1**	**<0.01**

P-values < .05 are printed in bold.

encouraging finding with regard to practical application. However, the distance between locations was limited and moreover, the height of the box was not varied in the current study. These are important limitations as previous studies found that different conditions (i.e. lifting height or box size) require different lifting techniques to minimize low-back load (Kingma et al., 2010, 2006, 2004). It is therefore necessary to examine the effect of feedback on low-back load over a greater variety of conditions. Next, we are unaware whether the results found in this study transfer to individuals with low-back pain. There are clear indications that people with low-back pain have alterations in low-back motor control (Hodges, 2001; Van Dieën et al., 2003) and they may therefore respond differently to feedback. Nevertheless, even if our findings do not transfer to people with low-back pain, feedback on low-back load appears a promising intervention in preventing low-back pain in groups at risk (Heneweer et al., 2011). Another limitation is that while we were able to reduce low back loading, the loading on the knee flexion increased, which could cause higher loading on the knee joints with possible implications for knee injury in the long term. This problem requires further investigation.

We used audio feedback but for practical applications vibrotactile feedback may be preferable. Another limitation is that we tested only one threshold value per feedback variable. Setting the threshold too high may be too easy and effects will be limited, setting the threshold value too low may result in constant feedback, which may frustrate the user while nothing is learned. An alternative option would be to gradual feedback, associated with the magnitude of the target variable, rather than using a threshold value. The time between feedback trials and the retention trial was limited and was roughly 5 min. This limited time was insufficient to actually explore retention, but did give us the possibility to examine the immediate effect of real-time feedback. This study demonstrated that participants are able to learn to change lifting behavior without knowing the source of the feedback, which may make it robust enough for use in a daily-life setting. Nevertheless, implementation in practice needs considerable care and careful evaluation, as previously Lavender et al. demonstrated that immediate effects on low back loading due to real-time feedback did not affect injury rates as compared to a control group (Lavender et al., 2007). Future work may compare our results with instructions, as lifting instructions appear to reduce peak moments as well (Kingma et al., 2004).

We did not explore between-participant differences within a certain feedback group, while we qualitatively did observe some differences in handling the feedback and reducing low back loading. Possible explanations for such differences may be anatomical in nature, such as stiffness in certain joints, or psychological, such as the eagerness to explore new lifting strategies. A detailed analysis is beyond the scope of this study, but might help to better understand how feedback may aid in reducing back loading in the future.

While our sample of participants is convenient, our moment feedback group had some imbalance in gender. However, we did not observe any noticeable differences between genders. Nevertheless, during further analysis, we did not observe any noticeable differences between genders.

In conclusion, real-time feedback in lifting is effective to reduce low-back load when the feedback variable is either the L5S1 moment or trunk inclination. Trunk inclination may have a practical application as it is easy to measure in daily life and, in the present study, it was just as effective in reducing low-back load as L5S1 moments. However, it should be thoroughly tested if this holds across a wider variety of tasks.

Declaration of Competing Interest

We declare that we have no Financial or personal relationships with other people or organizations that could inappropriately influence (bias) our work.

Acknowledgements

This work was supported by the european Unions Horizon 2020 through the SPEXOR project, contract no. 687662.

References

Agruss, C.D., Williams, K.R., Fathallah, F.A., 2004. The effect of feedback training on lumbosacral compression during simulated occupational lifting. Ergonomics 47, 1103–1115. https://doi.org/10.1080/00140130410001686375.

Ammendolia, C., Kerr, M.S., Bombardier, C., 2005. Back belt use for prevention of occupational low back pain: A systematic review. J. Manipulative Physiol. Ther. 28, 128–134. https://doi.org/10.1016/j.jmpt.2005.01.009.

Balagué, F., Mannion, A.F., Pellisé, F., Cedraschi, C., 2012. Non-specific low back pain. Lancet 379, 482–491. https://doi.org/10.1016/S0140-6736(11)60610-7.

Bergmann, A., Bolm-Audorff, U., Ditchen, D., Ellegast, R., Grifka, J., Haerting, J., Hofmann, F., Jäger, M., Linhardt, O., Luttmann, A., Meisel, H.J., Michaelis, M., Petereit-Haack, G., Schumann, B., Seidler, A., 2017. Do Occupational Risks for Low Back Pain Differ from Risks for Specific Lumbar Disc Diseases?: Results of the German Lumbar Spine Study (EPILIFT). Spine (Phila. Pa. 1976) 42, E1204–E1211. https://doi.org/10.1097/BRS.0000000000002296.

Coenen, P., Gouttebarge, V., Van Der Burght, A.S.A.M., Van Dieën, J.H., Frings-Dresen, M.H.W., Van Der Beek, A.J., Burdorf, A., 2014. The effect of lifting during work on low back pain: A health impact assessment based on a meta-analysis. Occup. Environ. Med. 71, 871–877. https://doi.org/10.1136/oemed-2014-102346.

Dickey, J.P., Mcnorton, S., Potvin, J.R., 2003. Repeated spinal flexion modulates the flexion – relaxation phenomenon. Clin. Biomech. 18, 783–789. https://doi.org/10.1016/S0268-0033(03)00166-9.

Faber, G.S., Kingma, I., van Dieën, J.H., 2011. Effect of initial horizontal object position on peak L5 / S1 moments in manual lifting is dependent on task type and familiarity with alternative lifting strategies. Ergonomics 54, 72–81. https://doi.org/10.1080/00140139.2010.535019.

Faber, G.S., Koopman, A.S., Kingma, I., Chang, C.C., Dennerlein, J.T., van Dieën, J.H., 2018. Continuous ambulatory hand force monitoring during manual materials handling using instrumented force shoes and an inertial motion capture suit. J. Biomech. 70, 235–241. https://doi.org/10.1016/j.jbiomech.2017.10.006.

Heneweer, H., Staes, F., Aufdemkampe, G., 2011. Physical activity and low back pain : a systematic review of recent literature. European Spine J., 826–845 https://doi.org/10.1007/s00586-010-1680-7.

Hodges, P.W., 2001. Changes in motor planning of feedforward postural responses of the trunk muscles in low back pain. Exp. Brain Res. 141, 261–266. https://doi.org/10.1007/s002210100873.

Hof, A.L., 1992. An explicit expression for the moment in multibody systems. J. Biomech. 25, 1209–1211. https://doi.org/10.1016/0021-9290(92)90076-D.

Hoy, D., Brooks, P., Blyth, F., Buchbinder, R., 2010. The Epidemiology of low back pain. Best Pract. Res. Clin. Rheumatol. 24, 769–781. https://doi.org/10.1016/j.berh.2010.10.002.

Kernozek, T., Iwasaki, M., Fater, D., La, C.D., 2006. Movement-based feedback may reduce spinal moments in male workers during lift and lowering tasks. Physiother. Res Int. 11, 140–147. https://doi.org/10.1002/pri.

Kingma, I., Bosch, T., Bruins, L., van Dieën, J.H., 2004. Foot positioning instruction, initial vertical load position and lifting technique: Effects on low back loading. Ergonomics 47, 1365–1385. https://doi.org/10.1080/00140130410001714742.

Kingma, I., De Looze, M.P., Toussaint, H.M., Klijnsma, H.G., Bruijnen, T.B.M., 1996. Validation of a full body 3-D dynamic linked segment model. Hum. Mov. Sci. 15, 833–860. https://doi.org/10.1016/S0167-9457(96)00034-6.

Kingma, I., Faber, G.S., Bakker, A.J., van Dieën, J.H., 2006. Lifting be reduced by placing one leg beside the object to be lifted ?. J. Phys. Ther. 86.

Kingma, I., Faber, G.S., van Dieën, J.H., 2010. How to lift a box that is too large to fit between the knees. Ergonomics 53, 1228–1238. https://doi.org/10.1080/00140139.2010.512983.

Kovacs, F.M., Zamora, J., Llobera, J., Ferna, C., 2004. Correlation between pain, disability, and quality of life in patients with common low back pain. Spine (Phila. Pa. 1976) 29, 206–210. https://doi.org/10.1097/01.brs.0000107235.47465.08.

Lavender, S.A., Lorenz, E.P., Andersson, G.B.J., 2007. Can a new behaviorally oriented training process to improve lifting technique prevent occupationally related back injuries due to lifting ?. Spine (Phila. Pa. 1976) 32, 487–494.

Sahar, T., Cohen, M., Neeman, V., Kandel, L., Odebiyi, D., Lev, I., Brezis, M., Lahad, A., 2008. Insoles for prevention and treatment of back pain. A survey of a Cochrane review. Cochrane Database Syst. Rev. 170, 4050–4053.

Schaafsma, F.G., Anema, J.R., Van Der Beek, A.J., 2015. Back pain: prevention and management in the workplace. Best Pract. Res. Clin. Rheumatol. 29, 483–494. https://doi.org/10.1016/j.berh.2015.04.028.

van Dieën, J., Dekkers, J.J.M., Groen, V., Toussaint, H.M., Meijer, O.G., 2001. Within-subject variability in low back load in a repetitively performed, mildly constrained lifting task. Spinal Cord 26, 1799–1804.

Van Dieën, J.H., Selen, L.P.J., Cholewicki, J., 2003. Trunk muscle activation in low-back pain patients, an analysis of the literature. J. Electromyogr. Kinesiol. 13, 333–351. https://doi.org/10.1016/S1050-6411(03)00041-5.

van Dieën, J.H., van der Burg, P., Raaijmakers, T.A., Toussaint, H.M., 1998. Effects of repetitive lifting on kinematics: Inadequate anticipatory control or adaptive changes?. J. Mot. Behav. 30, 20–32.

van Duijvenbode, I., Jellema, P., van Poppel, M., van Tulder, M., 2007. Lumbar supports for prevention and treatment of low-back pain (Review) Lumbar supports for prevention and treatment of low-back pain (Review). Cochrane Database Syst. Rev. 1–3. https://doi.org/10.1002/14651858.CD001823.pub2.This.