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Training can modify back muscle response to sudden trunk loading

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Abstract Sudden, unexpected loading to the trunk has been reported in the literature as a potential cause of low-back disorders. This study's aim was to investigate the effect of "readiness training" on the response to sudden back loading among untrained healthy individuals. The study included 19 participants and 19 matched controls. All were employees at the National Institute of Occupational Health. The participants received ten 45-min training sessions during a 4-week period. The training focused on reactions to a variety of expected and unexpected sudden trunk loadings, including balance and coordination exercises. Before and after the training, all subjects were tested for reaction to sudden trunk loading (SL). This entailed applying a horizontal force of 58 N to the subject's upper back. Elapsed time – measured between SL and stopping – decreased

significantly in the training group (from 337 to 311 ms) compared with the control group. The improved stopping time was associated with a changed EMG signal, characterized by an increase in the early parts of the response (up to 225 ms) and a subsequent decrease. EMG onset latency was unaffected by training. This study is apparently one of the first to demonstrate that the response to sudden trunk loading can be improved in healthy subjects without an increase in pre-activation and associated trunk stiffness. In perspective, the results indicate a possibility for a training-induced reduction of the risk of low-back injuries, e.g., in nurses exposed to sudden trunk perturbations during patient handling.

Keywords Exercise · Low-back pain · Biomechanics · Electromyography

Introduction

Low-back patients' reactions to sudden trunk loading and unloading differ from those of healthy control subjects. Magnusson et al. [6] and Wilder et al. [18] showed that – during a sudden back-loading incident – the erector-spinae EMG reaction times (or onset latencies) of low-back patients were longer than those of their matched controls. During a quick-release test, patients had longer reaction times for muscles shutting off (70 ms) and switching on (83 ms). In addition, patients had a different muscle-response pattern [12]. These differences between pa-

tients and healthy control people can be a reaction to the injury itself, or they may reflect an individual predisposing factor to low-back injuries.

Magnusson et al. [6] have demonstrated that training seems to alter the back-muscle response to sudden trunk loading in patients. After 2 weeks of rehabilitation, including specific training of coordination and posture control, patients' EMG reaction time and amplitude decreased. The quicker and "more efficient" reaction to sudden unexpected loading was supposed to reduce mechanical load on the spine.

It is, however, not known whether training can modify, or "fine-tune," healthy subjects' response to sudden trunk

loading. If it can, it should be possible to reduce the risk of low-back injuries in, for example, nursing personnel exposed to sudden trunk perturbations during patient handling. This would be a very practical discovery, as epidemiological and biomechanical studies emphasize sudden loading of the spine as a prominent risk factor for low-back injuries among health care workers [5, 6, 10, 14].

The EMG onset latency to a sudden, unexpected perturbation of the trunk has been reported at 70–150 ms [6, 12, 18]. The responses, generally believed to involve a transcortical pathway [3], have been termed long-latency reflexes, pre-programmed reactions, and M2-M3 or triggered reactions. Thus, the reflex should depend on the instruction to the subject and be modifiable by past experience, e.g., training. According to Latash [3], reproduction of the same perturbation amplitude in a series of trials leads to improved compensation due to the pre-programmed response. On the other hand, many studies, looking mainly at EMG reaction times, report or anticipate that the response to imposed perturbations is unaffected by trial number [6, 18].

EMG reaction times may, however, be insufficient to detect improvements in the execution of pre-programmed reactions. In a recent study, Skotte et al. [13] recorded EMG activity from the erector-spinae muscles and trunk-movement data during 10 trials of sudden loading of the low back. The analysis included EMG reaction time, and time elapsed until the trunk's forward movement stopped (stopping time). Reaction time ranged from 66 to 97 ms (79 ± 9 ms). No difference was found among the trials. On the other hand, the mean stopping time for the first trial was significantly longer than for subsequent trials. Apparently, the observed shortening of the stopping time with repeated trials was due to a more efficient pre-programmed response, not an improved reaction time. This was supported by the fact that, despite comparable reaction time, the EMG amplitudes during the period 50–250 ms after the sudden loading were higher in the trials with the short stopping time.

Consequently, when evaluating the response to sudden loading, it is important to analyze not only EMG onset latencies but also the mechanical changes and distribution of the EMG signal over time.

This feasibility study's aim was to investigate the potential effect of "readiness training" on the response to sudden back loading among untrained, healthy individuals. If a positive effect could be demonstrated in a laboratory set-up, it would seem that the prerequisites existed for initiating a large-scale training intervention in the healthcare sector.

Materials and methods

The training study included 19 participants (3 men and 16 women; mean age 35 years, range 23–54 years; mean height 1.71 m, range 1.60–1.90 m; mean weight 70 kg, range 49–90 kg) and 19 matched

Fig. 1 Set-up for sudden loading

controls (five men and 14 women; mean age 35, range 24–52; mean height 1.72 m, range 1.59–1.87 m; mean weight 67 kg, range 50–96 kg). Matching was done according to anthropometric measurements and age. All were healthy office workers or researchers at the National Institute of Occupational Health without a prior history of LBP (no one had received medical care for back pain). None of the subjects did regular physical training. None experienced back pain on the experimental days or during the intervention. All subjects gave informed written consent, and the local Ethical Committee approved the study.

The participants received ten sessions of 45 min supervised "readiness" training for 4 weeks. Training focused on reactions to a variety of expected and unexpected sudden trunk loadings, including balance and coordination exercises. Examples included: various "goalkeeper" exercises with light or heavy balls; jumping in a predefined pattern and frequency and being disturbed by rubber band connections to the other participants; and balance exercises on special equipment. The control subjects did not participate in training.

Before and after training, all subjects were tested for their reaction to sudden trunk loading (SL) generated by means of a special loading mechanism wired to a rigid bar attached to the subject's upper trunk (Fig. 1). The wire, connecting the load and the subject, ran over a reel. Thus, the gravitational force on the load (58 N) was transformed to a horizontal force applied to the subject. A potentiometer attached to the wire measured trunk movement. Subjects were fixed at the hip to obtain isolated trunk movements, and to avoid changes due to maintenance of postural stability. The SL was triggered randomly. Subjects were asked to stand as relaxed as possible and informed that in half a minute – but not exactly when – they would experience a sudden, moderate pulling forward, which they were asked to resist in order to maintain balance. The method is described in detail in Skotte et al. [13]. The sudden loading trial was repeated ten times during 6–9 min. One test trial preceded the 10 actual trials.

During the trial, pre-gelled Ag/AgCl surface electrodes recorded the EMG activity of the erector-spinae muscles. They were placed 3 cm apart on both sides of L3, approximately 3 cm lateral to the spinal column in the middle of the muscle belly. EMG signals were pre-amplified, high-pass filtered with a cut-off frequency of 10 Hz (1st order) and low-pass filtered with a cut-off frequency of 400 Hz with an 8th-order Butterworth filter. The amplified and filtered EMG signals and the potentiometer output for recording of the trunk position were sampled at 1000 Hz. Figure 2 shows EMG and potentiometer recordings from an SL experiment.

Fig. 2 EMG and potentiometer recordings from sudden-loading experiment. The sudden loading was executed at time zero

Analysis

The analysis of the sudden-loading trials included EMG reaction time, EMG amplitude and time elapsed until the trunk's forward movement stopped (stopping time). Reaction time was determined from the EMG recordings as the time between the trunk loading and the EMG onset. The EMG recordings were high-pass filtered, (2nd order), with a cut-off frequency of 25 Hz, and rectified. The investigator visually determined the EMG onset by means of a 2-s-long record (1 s before and after triggering of the sudden loading event) generated by computer program. The onset was determined as the point of the earliest rise in EMG activity beyond steady-state level [2]. The trials were presented to the investigator in a random and blinded manner, without identifying subject, trial and whether data came from the right or left erector spinae muscle.

The EMG signal was rectified and normalized according to EMG signals obtained from a standardized static back extension, performed at the test before and after the training intervention. In order to analyze EMG amplitude, the normalized signal was integrated in 25-ms intervals in the period from 50 ms to 325 ms after the sudden loading.

An automatic analysis was done for the trunk's stopping time and distance moved from the time of application of the load: the maximum of the curve representing trunk movement was detected, and time and distance corresponding to this point were read.

Statistics

A two-way ANOVA (analysis of variance) with subjects (random) and trials (fixed) as factors were used to look for differences between trials, and multiple comparisons were carried out using the post-hoc Tukey method. If there were no differences between the first or second measurement and trials 3–10, the mean of all 10 trials was used to analyze the training intervention's effect. Otherwise, the first and/or second trial was excluded in later analyses. The effect of training on stopping time, EMG onset latency and integrated EMG was analyzed by a mixed-model ANOVA. This took subjects as random factor, and group (training/control) and time (before/after) as categorical fixed factors for the interaction term between group and time. For integrated EMG data, mean values

for right and left were calculated before statistical analysis. A linear regression analysis was used to search for associations between changes in stopping time and changes in distance moved. The level of significance was set at $p < 0.05$.

Results

A two-way ANOVA (results not shown) did not reveal any significant differences between the first and second trials and trials 3–10 for any of the measurements of EMG onset latency, integrated EMG and stopping time. The execution of a test trial before the first actual trial apparently eliminated the learning effect demonstrated by Skotte et al. [13]. Therefore, the mean of all 10 trials before and after training could be used to analyze the effect of training.

Figure 3 shows means and SD for stopping time, before and after the training intervention. The mixed-model ANOVA showed that stopping time decreased significantly in the training group compared with the changes in the control group. The training group's stopping time improved by 7.8%, which corresponds to an effect size (mean before - mean after /SD) [1] of 0.53. A linear regression showed a significant association ($p = 0.000$; $r = 0.72$) between the changes in stopping time and changes in peak trunk flexion (distance moved). Training did not affect the EMG reaction time (EMG onset latency). Table 1 shows the re-

Fig. 3 Means of stopping time before and after the training intervention. Bars denote standard error of means. *Significant change (ANOVA) in the training group compared with the control group ($p = 0.029$)

Table 1 EMG onset latencies (ms) before and after the training intervention. Figures are estimates of mean (SE). The p value denotes the significance of the 0-hypothesis of no interaction between group and time

	Training group ($n=19$)		Control group ($n=19$)		p value
	Before	After	Before	After	
Right	91.4 (2.5)	90.7 (2.5)	90.0 (1.5)	89.3 (1.7)	0.20
Left	100.8 (2.1)	90.7 (2.1)	90 (1.4)	89.9 (1.5)	0.31

Fig. 4 Changes in rectified, normalized integrated EMG in the training group ($n=14$). Absolute differences (after–before) are illustrated in intervals of 25 ms. Only participants with faster stopping times after the intervention are included. Two participants (with faster stopping times) were excluded from the figure because of severe EMG-noise

sults of a mixed-model ANOVA. There was no main effect on EMG reaction time after the intervention.

Mixed ANOVA analysis showed no overall changes in integrated EMG in the training group, compared with the control group (from 50–325 ms after SL). However, significant differences between the changes in the training and control groups were found when integrated EMG signals were analyzed for shorter time periods. In the period from 125 to 225 ms, the training group exhibited an increase in EMG activity [122% of reference-EMG·s to 160% of reference-EMG·s; $p=0.048$ (mixed ANOVA)]. This was followed by a concomitant decrease in the period from 225 ms to 300 ms [89% of reference-EMG·s to 57% of reference-EMG·s; $p=0.050$ (mixed ANOVA)].

Figure 4 presents a detailed description of these changes in the time-wise distribution of the EMG response in subjects with an improved (more than 5 ms faster) stopping time after training. EMG changes are shown for successive 25-ms time sequences following the sudden loading.

Discussion

In this study, training had an impact on the subject's reaction to sudden trunk loading. Stopping time decreased significantly in the training group, compared with the control group (Fig. 3). The effect size was 0.53 standard deviations, which is considered moderate [16]. However, taking into account that training lasted only 1 month, the results were substantial.

As there were no changes in EMG-latency, the improved stopping time after readiness training apparently resulted from more efficient EMG response. Figure 4 illustrates how improvement in stopping time was associated with a changed EMG signal, characterized by an increase in the early parts of the response (up to 225 ms) and a subse-

quent decrease. In addition, the EMG signal exhibited a minor suppression prior to the initial burst, which was moved forward in time. This suppression-response may be part of the programmed responses. Interestingly, a silent period prior to the EMG burst has been reported to optimize and increase peak muscular force [7]. Considering an electromechanical delay of erector-spinae muscle around 130 ms [17], the shift to the left of the integrated EMG – with peak activity around 175 ms – fits nicely with an improved stopping time of 311 ms after training (Fig. 3). Improved stopping time is supposed to reduce the risk of low-back injuries, because a faster reaction could decrease the energy accumulated before the trunk's forward movement slows. Furthermore, in this study, trunk flexion in response to a perturbation decreased in people with faster stopping times. This indicates that training could reduce the risk of low-back injuries, e.g., in nursing personnel exposed to sudden trunk perturbations during patient handling.

The range of reaction times (Table 1) found in this study is comparable with data reported in the literature. The first response to a sudden trunk loading occurred with onset latencies corresponding to long latency-stretch reflexes or pre-programmed muscle responses. No cases elicited the very fast M1 response of approximately 12 ms reported in experiments using direct taps on the paraspinal muscles [15].

The lack of EMG-latency changes found in this study appeared to disagree with the results of studies in which low-back patients decreased EMG onset latency after training rehabilitation [6, 18]. In addition, patients who had the most severe pain on entering the program improved more than patients with less pain [6, 18]. However, the determination of EMG onset latencies becomes difficult in the presence of high EMG activity before the sudden loading event. High background activity is likely to mask the very first increase in activity, which is clearly detectable if the

pre-activity is low [13]. Subjects suffering from low-back disorders are known to show higher pre-EMG activity than healthy subjects [11]. Consequently, it is possible that the improvement in EMG-reaction times after rehabilitation, as reported by some of these studies, may have been biased by a simultaneous reduction in pre-EMG activity due to improved pain status. The changes in mechanical response (stopping time) and EMG-response pattern found in the present study have not previously been reported.

Previous studies – Nielsen et al. [9], looking specifically at H-reflexes, and Mortimer and Webster [8], studying the M3 component in karate-trained subjects – have suggested that training can modify different components of the stretch reflex. However, this study appears to be one of the first to demonstrate that the response to sudden trunk loading can improve in a normal subject without an increase in pre-activation and associated trunk stiffness [4]. Still, some caution

is warranted in interpreting the results. As shown in Fig. 3 the mean stopping time prior to the intervention was faster in the control group than in the training group (Fig. 3), a difference that leveled off after training. In this study, there was a significant association between the changes in stopping time and the original stopping time. This could reflect the possibility that only subjects with a slower-than-average response time can improve their reaction, and not beyond the results obtained in a “normal group.”

The mere fact that training can affect the pre-programmed response and fine-tune the EMG response in a lab setting is nevertheless promising. Results from this feasibility study will soon be tested in a large field study with more intensive training and more comparable groups. The study will investigate the effect of on-the-job training on the muscular responses to unexpected perturbations in nursing personnel.

References

- Cohen J (1969) Statistical power analysis for the behavioral sciences. 2nd edn. Academic Press, New York
- Hodges PW, Bui BH (1996) A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroencephalogr Clin Neurophysiol* 101(6):511–519
- Latash ML (1998) Neurophysiological basis of movement. *Human Kinetics*. Champaign, Illinois
- Lavender SA, Marras WS, Miller RA (1993) The development of response strategies in preparation for sudden loading to the torso. *Spine* 18(14): 2097–2105
- Lavender SA, Shakeel K, Andersson GBJ, Thomas JS (2000) Effects of a lifting belt on spine moments and muscle recruitments after unexpected sudden loading. *Spine* 25(12): 1569–1578
- Magnusson ML, Aleksiev A, Wilder DG, Pope MH, Spratt K, Lee SH, Goel VK, Weinstein JN (1996) Unexpected load and asymmetric posture as etiological factors in low back pain. *Eur Spine J* 5:23–35
- Mortimer JA, Eisenberg P, Palmer SS (1987) Premovement silence in agonist muscles preceding maximum efforts. *Exp Neurol* 98(3):542–554
- Mortimer JA, Webster DD (1983) Dissociated changes of short- and long-latency myotatic responses prior to a brisk voluntary movement in normals, in karate experts, and in Parkinsonian patients. *Adv Neurol* 39:541–554
- Nielsen J, Crone C, Hultborn H (1993) H-reflexes are smaller in dancers from the Royal Danish Ballet than in well-trained athletes. *Eur J Appl Physiol Occup Physiol* 66(2):116–121
- Owen BD (1986) Personal characteristics important to back injury. *Rehabil Nurs* 11(4):12–16
- Pope MH, Aleksiev A, Panagiotacopoulos ND, Lee JS, Wilder DG, Friesen K, Stielau W, Goel VK (2000) Evaluation of low back muscle surface EMG signals using wavelets. *Clin Biomech (Bristol, Avon)* 15(8):567–573
- Radebold A, Cholewicki J, Panjabi MM, Patel TC (2000) Muscle response pattern to sudden trunk loading in healthy individuals and in patients with chronic low back pain. *Spine* 25(8): 947–954
- Skotte JH, Fallentin N, Pedersen MT, Essendrop M, Strøyer J, Schibye B (2002) A new set-up for studying sudden loading of the low back. *J Biomechanics* (submitted)
- Smedley J, Egger P, Cooper C, Coggon D (1995) Manual handling activities and risk of low back pain in nurses. *Occup Environ Med* 52:160–163
- Tani T, Yamamoto H, Ichimiya M, Kimura J (1997) Reflexes evoked in human erector spinae muscles by tapping during voluntary activity. *Electroencephalogr Clin Neurophysiol* 105: 194–200
- Thomas JR, Salazar W, Landers DM (1991) What is missing in p less than .05? Effect size. *Res Q Exerc Sport* 62(3):344–348
- van Dieen JH, Thissen CE, van de Ven AJ, Toussaint HM (1991) The electromechanical delay of the erector spinae muscle: influence of rate of force development, fatigue and electrode location. *Eur J Appl Physiol Occup Physiol* 63(3–4):216–222
- Wilder DG, Aleksiev AR, Magnusson ML, Pope MH, Spratt KF, Goel VK (1996) Muscular response to sudden load. *Spine* 21(22):2628–2639