International Journal of Industrial Ergonomics 64 (2018) 163–169

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Biomechanical characteristics in the recovery phase after low back fatigue in passive and active tissues

Sangeun Jin

The Human and Safety Engineering Laboratory, Department of Industrial Engineering, Pusan National University, Busan, 46241, Republic of Korea

ARTICLE INFO

Article history:
Received 21 July 2017
Received in revised form
20 October 2017
Accepted 21 January 2018

Keywords:
Lumbar spine
Flexion-relaxation phenomenon
Recovery
Passive tissue elongation
Muscle fatigue

ABSTRACT

Previous studies have shown how abnormal low back conditions can increase the risk of low back pain (LBP) by using the flexion-relaxation phenomenon (FRP) to provide insights into the function of the lumbar spine around the full flexion. However, the characteristics of each abnormal condition during the recovery phase remain poorly understood. To expand our knowledge in this area, twelve subjects performed the following three protocols on three different days: (1) passive tissue elongation (PTE), (2) muscle fatigue (MF), and (3) its combination (PTE & MF). The lumbar angle at which FRP of the lumbar muscles is initiated (electromyography (EMG)-off point) and the full lumbar flexion angle were captured before and after the protocols and during the subsequent 40-min recovery period. Results showed no recovery in EMG-off point after PTE until 40 min of rest, but a rapid recovery in 5 min of rest after MF. The combined protocol did not exhibit any boosting effect by an interaction between muscle fatigue and stress-relaxation in passive tissues, but rather the trend closely mirrored the PTE recovery. However, the combined protocol demonstrated gradual recovery after 40-min resting time in both kinematic measures, although the EMG-off points and the full lumbar flexion angle were not fully recovered. These results suggest that the slow recovery of the viscoelastic tissues caused by the prolonged stooping of PTE and PTE&MF may lead to longer spinal instability than low back muscle fatigue.

Relevance to industry: For workers performing various manual material handling tasks for up to 8 h daily, knowledge about the recovery phase from any abnormality can help develop an appropriate work-rest and job rotation schedule.

1. Introduction

In many industrial settings, workers perform various trunk flexion-extension motions for prolonged periods including manual lifting, prolonged stooping, and repetitive stooping (Gallagher and Hamrick, 1991). Such tasks cause the known low back risk factors such as low back muscle fatigue and stress-relaxation of the low back passive tissue (Goldsheyder et al., 2002; Kelsey et al., 1984; Magora, 1973; Marras et al., 1993; Rosecrance et al., 2006; Jin et al., 2009). Abnormal low back conditions have been widely investigated to understand the nature of low back pain (LBP) and provide practical methods for prevention. Unfortunately, no clear guidance for a work-rest schedule over the working time has been developed, because the severity of each risk factor after the task (i.e., However, due to the variety of workstation designs and the complexity of working schedule, our knowledge of LBP prevention remains incomplete. recovery trend) is not well-documented. The significance of any abnormality during or right after the task has been the focus of LBP rather than recovery from the abnormality.

Some previous studies investigated biomechanical responses during the recovery phase after creep of lumbar viscoelastic tissues and fatigue of lumbar muscles. In previous studies focusing on the characteristics of recovery phase from low back muscle fatigue, an exponential time process was generally suggested in that a rapid recovery (in heart rate, breathing depth, systolic blood pressure, oxygen uptake, blood lactate elimination and metabolic changes in a muscle) was observed in the very early phase of the rest period, followed sequentially by a slowdown in the recovery phase (Sahlin and Ren, 1989; Petrofsky, 1981). Consequently, a review study focusing on the influence of low back muscle fatigue suggested that periodic short-rest breaks can significantly improve perceived discomfort during repetitive work (Santos et al., 2016). Meanwhile, in an *in-vivo* study considering the recovery in low back electromyography (EMG) signal (i.e., mean power frequency), a shorter

E-mail address: sangeunjin@pusan.ac.kr.

https://doi.org/10.1016/j.ergon.2018.01.014
0169-8141/

recovery time than the fatigue developing time was observed after dynamic lifting task. Nine minutes of lifting and lowering 25% of individual maximum voluntary contraction (MVC) at a frequency of 4 lifts/min showed full recovery in 90% of subjects in the symmetric task and 50% of subjects in the asymmetric task after 5 min of rest (Shin and Kim, 2007). Those in-vivo studies suggested a fast initial recovery very earlier in the rest time, although the recovery time depends on the types of task, fatigue developing time, and individual characteristics. Contrary to the biomechanical evidence, Christian and Nussbaum (2015) showed a sensitivity of the biomarker such as interleukin-6 and creatine kinase, obtained from the blood sample, to confirm the low back muscle fatigue, and suggested that both biomarkers could be recovered by 24 h after the 1-h lifting task. In summary, even though the rapid recovery of the biomechanical response was suggested by some previous studies, investigating various low back responses during the longer recovery period is necessary for better understanding of the nature of recovery in the low back fatigue.

Meanwhile, our present knowledge on passive tissue fatigue and its recovery still remains limited. Shin and Mirka (2007) investigated changes in the full lumbar flexion angle and extensor muscle activities around full flexion during 10 min of prolonged stooping protocol and another 10 min of recovery session. Results revealed significant increases in both full lumbar flexion angle and normalized EMG (NEMG) after the static stooping protocol, but the 10-min standing recovery did not fully recover the stress-relaxation of the low back passive tissues. In an animal model study, Solomonow et al. (2003c) conducted an in-vivo study using a live feline model to reveal the effect of creep of lumbar viscoelastic tissues on spinal reflexes. A series of three 10-min static flexions, using an S-shaped hook inserted around the supraspinous ligaments, was performed with each session followed by 10-min resting on the spine of the feline model. After a 7-h resting period, no full recovery of the creep was developed in the passive tissues. Also, hyper-excitable spinal reflex responses, which are a form of rapid, automatic response (e.g., muscle activation) to specific stimuli, were observed in the first 20–30 min and lasted until the end of the 7-h rest session. In summary, these studies may suggest a long recovery phase after viscoelastic creep in passive tissues and provide a good empirical basis to understand the recovery process. However, these studies are limited by their use of a feline model instead of human subjects and their implementation of a mere 10-min recovery session with human subjects. Also, they only observed the peak lumbar flexion angle in trunk kinematics.

The flexion-relaxation phenomenon (FRP) shows the changes in the nature of passive and active tissues in the low back under abnormal conditions in that the phenomenon explains a load sharing mechanism between the passive and active tissues (Fick, 1911; Schultz et al., 1985). As prolonged stooping also affects the low back muscles by passively stretching their length, introducing a new variable such as FRP could reveal various characteristics during the recovery phase. Recent studies focusing on the trunk motion rhythm under the low back muscle fatigue condition demonstrated significantly larger lumbar-pelvic rotation rhythm with bigger L5/S1 joint moments (Hu and Ning, 2015a, 2015b). It may suggest a negative influence of the lumbar muscle fatigue on the trunk motion coordination, and a possibility to change the biomechanical equilibrium point between the passive tissues and the active tissues in low back during trunk flexion-extension. A pairwise comparison by using FRP among low back muscle fatigue, passive tissue elongation and the combination of both may provide a better understanding of the recovery phase.

The goal of the current *in-vivo* study was to compare and investigate the recovery phase after three different types of low back fatigue conditions, namely stress-relaxation of the low back passive tissues, low back muscle fatigue and the combination of both. Observation during the recovery phase is important in work station design in that workers are asked to perform repetitive, prolonged stooping or lifting over the working time of up to 8 h daily. It is hypothesized that the passive tissue relaxation condition requires a significantly longer recovery time than does low back muscle fatigue. Also, the combined effect may have a weak effect of passive tissue elongation in very earlier stage of the recovery time, but similar or longer time for full recovery regarding the negative boosting of the combined effect.

2. Methods

2.1. Participants

Twelve male participants were recruited from among the undergraduate and graduate students at Iowa State University. The participants did not report any pain or symptoms in the low back and lower extremities. Prior to participation, each participant provided written informed consent, approved by the institutional review board of Iowa State University. The average and standard deviation of age, height and whole body mass of the participants were 28.3 (SD 4.7) years, 175.9 (SD 2.7) cm, and 73.5 (SD 6.6) kg, respectively.

2.2. Apparatus

A lumbar dynamometer (Marras and Mirka, 1989) was used to capture MVCs in both trunk flexion and extension that require static resistance. Surface EMG was used to measure muscle activation patterns in right and left pairs of L4 paraspinals (2 cm lateral from L4 spinous process), L3 paraspinals (4 cm lateral from L3 spinous process), rectus abdominis, external oblique, gluteus maximus and biceps femoris (Model DE-2.1, Bagnoli™, Delsys, Boston, MA) (data collected at 1024 Hz). In the current experiment setting, the antagonistic and synergistic muscles (i.e., rectus abdominis, external oblique, gluteus maximus and biceps femoris) were included for our companion papers investigating the role of each muscle in trunk flexion-extension before (TIME 0) and after (TIME 1) the 10 min protocols. To reveal recovery characteristics during 40 min recovery session (from TIME 0 ~ TIME7), only relevant variables such as EMG-off angles and peak lumbar flexion angle, revealing interaction between low back muscles and passive tissues, were included. Consequently, only low back muscles (L4 and L3 paraspinals) were used for data analysis. A magnetic field-based motion analysis system captured the instantaneous trunk motions at 102.4 Hz (Ascension Technology Corporation, Shelburne, VT). Two magnetic sensors were placed over the S1 and T12 vertebrae.

2.3. Experimental design

The recovery characteristics in the three protocols (passive tissue elongation (PTE), muscle fatigue (MF), and the combination of both (PTE & MF)) were studied. Each protocol was performed for 10 min after measuring baseline (TIME 0). To reveal the difference in recovery phase, an independent variable (TIME) was employed with eight levels: 1) TIME 0 (baseline), 2) TIME 1 (after 10-min protocol), 3) TIME 2 (after 5-min resting), 4) TIME 3 (after 10-min resting), 5) TIME 4 (after 15-min resting), 6) TIME 5 (after 20-min resting), 7) TIME 6 (after 30-min resting), and 8) TIME 7 (after 40-min resting). Only the TIME was considered as an independent variable in the current experiment design. For a comparison among the protocols, each protocol was standardized, and the recovered TIME to the baseline was used for a comparison criterion.