Optimum design of a lumber support belt to reduce the physical workload of the low back

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Abstract
Low back pain is a major medical problem frequently encountered in the field of occupational health, and lumber support belts are often used for the prevention and treatment of low back pain. This study investigated the effect of width (60, 90, 120, and 150 mm) and thickness (1, 2, 3, and 4 layers) of lumber support belts on the physical workload of the low back in order to optimize these lumber support belt parameters and thus minimize workload. Subjects performed a bandage-wrapping task with and without the use of a lumber support belt. The trunk segment was divided into 3 areas: the chest, abdomen, and pelvis. The chest, abdominal, and pelvic angles were measured, and the L5/S1 compression force was estimated. In addition, subjective scores of perceived abdominal discomfort and perceived difficulty of the bandage-wrapping task were measured. We found that the use of a lumber support belt during this task decreased the abdominal angle and increased the chest and pelvic angles while reducing the L5/S1 compression force. A wider lumber support belt increases compression forces, perceived discomfort, and perceived difficulty of the task, whereas a thicker lumber support belt increases perceived discomfort. Optimization results showed that a 60-mm-wide, 3-layer lumber support belt is the most effective in reducing the workload of the low back during a task involving trunk flexion.

Key words: Ergonomics, Occupational biomechanics, Lumber support belt, Low back pain, Working posture, Optimization, Response surface method

1. Introduction

Low back pain (LBP) is a major medical problem frequently encountered in the field of occupational health. The Japanese government reported that LBP is the cause of approximately 60% of occupational injuries requiring more than 4 days of rest (Ministry of Health, Labour and Welfare, 2013). Nurses frequently experience occupational LBP, and more than 70% of Japanese nurses have reported LBP (Wada, 2006). A questionnaire survey of Japanese nurses found that tasks causing LBP, such as changing diapers, providing transfer assistance, changing a patient’s position, and making beds, always require trunk flexion (Kokubo et al., 2000). The National Institute for Occupational Safety and Health regards trunk flexion as an awkward working posture and has reported an association between trunk flexion and LBP (NIOSH, 1997). Smedley et al. (1997) reported that approximately 40% of nurses developed LBP during a follow-up period of approximately 19 months, and approximately 10% of these nurses experienced pain that led to work absences. Therefore, reducing the physical workload of the low back is important in order to prevent LBP among workers who frequently bend forward, such as nurses.

Lumber support belts (LSBs) are often used for the prevention and treatment of LBP (Dillingham, 1998) and are a
feasible therapeutic option for workers with LBP (Jellema et al., 2002; Roelofs et al., 2010). The use of LSBs has the advantage that it can be used at a relatively low cost compared with mechanical aids. Grew and Deane (1982) suggested that LSBs have therapeutic value for preventing LBP because they limit movement, alternate intracavity pressures, modify of muscle actions, and warm the skin. Roelofs et al. (2007) reported that subjects who wore LSBs had fewer days with LBP than subjects who did not wear LSBs, and they concluded that the use of LSBs may prevent LBP. Calmels et al. (2009) also concluded that the use of LSBs may alleviate LBP. However, some systematic reviews have found no evidence in favor of the use of LSBs for primary prevention of LBP in the workplace (van Poppel et al., 2004; van Duijvenbode et al., 2008). Thus, there is conflicting evidence regarding the effectiveness of LSBs for the prevention and treatment of LBP. However, many reports have concluded that the use of LSBs limits trunk flexion (Grew and Deane, 1982; Thoumie et al., 1998; van Poppel et al., 2000; Cholewicki et al., 2010; Larivière et al., 2014).

Our previous research investigated the effects of LSB use on working posture and physical workload during a trunk flexion task that modeled wrapping a bandage (Nishijima et al., 2015). The results showed that use of an LSB reduced the trunk flexion angle and lumbosacral disc (L5/S1) compression force and improved subjective discomfort, although electromyograms showed no change in trunk muscle activity. However, we have not previously investigated the influence of LSB parameters, such as the width and thickness of the belt, on physical workload. Other researchers have investigated the relative effects of several types of LSBs on lumber movement limitation (Cholewicki et al., 2010; Larivière et al., 2014), but they have not quantitatively evaluated the effects of belt parameters on physical workload. These LSB parameters should be evaluated quantitatively in an attempt to minimize physical workload.

Therefore, the objective of this study was to investigate the effects of LSB parameters as well as optimize these parameters to minimize physical workload during a nursing task involving trunk flexion. In this case study, a bandage-wrapping task involving trunk flexion, which is the same task used in our previous research, was used. We assumed that both the width and the thickness of the front part of the LSB would affect the trunk flexion limitation and physical workload reduction, because the front part of the belt is attached to the body during trunk flexion. In this study, the trunk was split into 3 segments (chest, abdomen, and pelvis), and the forward tilt angles of each segment were measured. The L5/S1 compression force was estimated using biomechanical analysis. In addition, subjective scores measuring perceived abdominal discomfort and task difficulty were obtained. The response surfaces of the L5/S1 compression force and 2 subjective scores were approximated and optimized, and the optimum LSB parameters were then obtained.

2. Material and Methods

2.1. Subjects

Eleven healthy Japanese male subjects, aged between 21 and 24 years, participated in this study. All subjects were university students, and none had LBP. Their mean (standard deviation) stature and body mass measurements were 169.3 (6.08) cm and 62.7 (6.16) kg, respectively. This study was approved by the Research Safety and Ethics Committee of the Hino campus of Tokyo Metropolitan University.

2.2. Experimental conditions

The LSB used in this study consisted of an abdominal belt, elastic support belt, and plastic stay (Fig. 1). The abdominal and elastic support belts are made of extensible materials (polyurethane, polyester, and nylon), and the plastic stay is made of polypropylene. The abdominal belt is fixed by a hook and loop fastener just below the umbilicus, and the elastic support belt is then fixed to adjust the degree of constriction. The experimental factors in this study were width ($w$) and thickness ($t$) of the abdominal belt. The width and thickness were 60, 90, 120, or 150 mm and 1, 2, 3, or 4 layers, respectively. The thickness was controlled by overlapping the textiles; thus, $t$ is a discrete variable, whereas $w$ is a continuous variable. The dimensions of these 2 parameters were based on an existing commercial LSB (SACRO Vivanurse, ALCARE Co., Ltd.) with $w = 90$ mm and $t = 1$ layer. All other dimensions were the same as those of the existing LSB. The abdominal belt was fixed at 1.3 times its natural length so as to standardize the degree of constriction. The elastic support belt was arbitrarily fixed by each subject so that it could be worn without discomfort.

Figure 2 shows the experimental environment of the bandage-wrapping task. A plastic pipe, which is simulated as a
patient’s arm with diameter of 6 cm, was fixed on a lifting platform was adjusted to 30% of the subject’s stature. The wrapping area of the pipe was set at 25 cm. The distance from the end of the wrapping area to the toes of each subject was arbitrarily determined by each subject, but constant distances were used for each subject irrespective of the LSB conditions. The mean (standard deviation) of this distance for all 11 subjects was 7.69 (4.83) cm. In addition to the 16 LSB conditions, an experiment in which subjects did not use an LSB was conducted. Therefore, the total number of experimental conditions was 17.

![Fig. 1 LSBs used in this study. Each LSB has a different width and thickness.](image)

2.3. Experimental procedure

Each subject was told the aim of the study and gave his informed consent. The subjects were instructed to (1) keep the bandage attached to the pipe during wrapping, (2) slide one-third of the width of the bandage during each cycle, and (3) wrap the bandage tight, without wrinkles. Before the experiment, all subjects had enough bandage-wrapping practice to avoid a learning effect.

As the initial posture of each trial, the subjects were required to keep their knees straight while bending their trunk and attach the bandage to the pipe. They started the wrapping task with the examiner’s signal and continued wrapping for 30 s. If a subject finished wrapping the entire area in less than 30 s, he maintained the trunk flexion posture until the end of the 30-s period. Five-minute breaks were taken in-between each trial, and subjective evaluations were measured during the break. In addition, the measuring sequence was randomized to minimize any confounding related to order of exposure.

2.4. Measurements

2.4.1. Working posture

In this study, the chest, abdominal, and pelvic angles were measured to determine the effects of LSB use. The
forward tilt angles were defined as follows (Fig. 3):

- Trunk angle: angle between the vertical line and the line connecting the shoulder and hip joints
- Chest angle: forward tilt angle of the chest with the abdomen
- Abdominal angle: forward tilt angle of the abdomen with the pelvis
- Pelvic angle: forward tilt angle between the pelvis and a vertical line

Three 3D sensors (TSND121, ATR-Promotions, Inc.) were attached at the back side of the median line at the following heights: the angulus inferior scapulae (chest), approximately half the height between the lowest point of the tenth costa and the iliac crest (abdomen), and the greater trochanter (pelvis). The tilt angles of each sensor were obtained 5, 10, 15, 20, and 25 s after the beginning of the task, and the defined angles were calculated for each measuring point. The average angles of the 5 measuring points were used to represent the values for a corresponding LSB condition. A 2D biomechanical analysis was performed based on the measured working postures so as to estimate the L5/S1 compression force ($F_c$). The estimated compression force was used as an indicator of physical workload during the bandage-wrapping task. $F_c$ was determined using the following equation (Chaffin et al., 2006):

$$F_c = F_{L5S1} + M_{AP}/L_{AP}$$

where $F_{L5S1}$, $M_{AP}$, and $L_{AP}$ are the normal component of body weight on the L5/S1 disc, the moment around the L5/S1 imposed by the body weight, and the moment arm between the back muscles and the L5/S1, respectively. $L_{AP}$ and the weight and center of gravity of each body segment were obtained from Chaffin et al. (2006).

Fig. 3 Definition of the angles measured. The trunk was split into chest, abdominal, and pelvic segments. The chest, abdominal, and pelvic angles were measured in addition to the trunk angle.

2.4.2. Subjective evaluation

Perceived abdominal discomfort and perceived difficulty of the bandage-wrapping task were rated on a scale of 1 to 7. For abdominal discomfort, 1 and 7 represent “very slight discomfort” and “very severe discomfort,” respectively. For task difficulty, 1 and 7 represent “very easy” and “very difficult.” Therefore, lower subjective scores are desirable. Perceived abdominal discomfort was not measured in the no-LSB condition.

2.4.3. Statistical analysis

A 2-factor analysis of variance (ANOVA) was conducted at the 5% significance level to investigate the effects of LSB width and thickness on the L5/S1 compression force and subjective scores. The width and thickness, and the subject, were set as control factors and the block factor, respectively.

2.5. LSB optimization

The radial basis function (RBF) network (Orr, 1996) was used to predict the response surfaces of the L5/S1 compression forces, perceived discomfort, and task difficulty, represented as $C(w, t)$, $P(w, t)$, and $D(w, t)$, respectively.
The RBF network performs well in terms of accuracy and robustness, irrespective of the degree of nonlinearity. Additionally, it is robust against experimental errors or noise (Jin et al., 2001). A detailed procedure for constructing a response surface using the RBF network is provided in the Appendix. The predicted response surfaces were minimized, and the optimum LSB parameters were obtained.

3. Results

3.1. Working posture and L5/S1 compression force

The effect of LSB width was significant for all 4 measured angles: the trunk \(F(3, 30) = 5.39, p < 0.05\), chest \(F(3, 30) = 13.6, p < 0.05\), abdomen \(F(3, 30) = 5.03, p < 0.05\), and pelvis \(F(3, 30) = 8.49, p < 0.05\). LSB thickness had no effect on any of the angels measured. Figure 4 shows the average trunk, chest, abdominal, and pelvic angles measured during the bandage-wrapping task in subjects wearing or not wearing an LSB. The differences in trunk angles among the different LSB conditions were approximately less than 7° and were similar to those measured in the no-LSB condition. The chest angles measured in subjects using LSBs were similar to or higher than those measured in those not using an LSB. The chest angle increased with decreasing LSB width, and LSBs with a width of 60 mm produce relatively high chest angles. The abdominal angles measured for all LSB conditions were lower than those measured in the no-LSB condition. The abdominal angle increased with increasing LSB width. The pelvic angles were higher for all LSB conditions than in the no-LSB condition. The pelvic angle increased with increasing LSB width, and relatively lower compression forces were found when the width was 60 mm, except with 1 layer of thickness.

The effect of LSB width was significant for the L5/S1 compression force \(F(3, 30) = 7.79, p < 0.05\), whereas the effect of thickness was not significant. Fig. 5 shows the average estimated L5/S1 compression forces of all subjects. The compression force measured without an LSB was 1854 N, and LSB forces ranged from 1700 to 1853 N. Compression force increased with increasing LSB width.

![Fig. 4 Average tilt angles of each segment during the bandage-wrapping task with and without LSBs. The error bars represent standard deviation.](image-url)
3.2. Subjective scores

The effects of both width \([F(3, 30) = 17.9, p < 0.05]\) and thickness \([F(3, 30) = 5.22, p < 0.05]\) on perceived abdominal discomfort were significant. LSB width influenced perceived difficulty of the task \([F(3, 30) = 3.34, p < 0.05]\), whereas thickness had no significant effect. Figure 6 shows the average subjective scores of all subjects. Perceived abdominal discomfort increased with increasing width and thickness of the LSB. Perceived task difficulty shows an increasing trend with increasing LSB width. In addition, the perceived difficulty scores for all LSB conditions were higher than those of the no-LSB condition.

3.3. Optimum solutions

The average absolute errors of the response surfaces for the L5/S1 compression forces, perceived abdominal discomfort, and perceived difficulty of the bandage-wrapping task were 0.914 N, 0.0211, and 0.0163, respectively. Table 1 shows the optimum solutions and predicted values of each indicator. In addition, Table 1 describes the degree of improvement in the optimum solutions on the compression force and the difficulty of the task compared with the without LSB condition. The optimum solutions were obtained at \((w, t) = (60.0 \text{ N, 2 layers})\) for the compression force and the perceived discomfort and \((105.9 \text{ N, 1 layer})\) for the difficulty of the task. The compression force and the difficulty were improved (153 N and 0.196, respectively) compared with the no-LSB condition.
Table 1: Optimum solutions for L5/S1 compression force, perceived abdominal discomfort, and perceived difficulty of the bandage-wrapping task.

| Indicators                      | Optimum solutions | Predicted response surface value | Improvement vs no LSB |
|--------------------------------|-------------------|----------------------------------|-----------------------|
|                                | Width w [mm]      | Thickness t [layer]*              |                       |
| L5/S1 compression force        | 60.0              | 2                                | 1702 N                | -153 N                |
| Perceived discomfort           | 60.0              | 2                                | 2.71                  | NA                    |
| Perceived task difficulty      | 105.9             | 1                                | 2.29                  | -0.196                |

*LSB thickness is under the integer constraint.

4. Discussion

Use of LSBs increased the chest and pelvic angles by approximately 3.1° and 3.7° and decreased the abdominal angle by approximately 10.6°. These changes are imposed by LSB restriction of abdominal excursion, as the LSB is worn between the abdomen and pelvis (Fig. 7). Therefore, the chest and pelvic angles increased to compensate for the reduction in the abdominal angle in order for subjects to maintain their reach into the working area. The moment arm for trunk weight around the L5/S1 disc is reduced by the abdominal angle reduction; thus, the use of LSBs reduces the L5/S1 compression force. Therefore, LSBs effectively reduce the physical workload of the low back during trunk flexion tasks.

The width of LSB affected all 3 study indicators, whereas LSB thickness only affected perceived abdominal discomfort. Therefore, when designing an LSB, determining the appropriate width is more important than determining the thickness. The top edge of a wide LSB reaches the costae, which restricts chest excursion. Therefore, a wider LSB produces a lower chest angle and higher abdominal and pelvic angles. The 3 segment angles with wider LSB are closer to those obtained in the no-LSB condition; thus, wider LSBs increase the L5/S1 compression force. For the 60-mm-wide LSB, which had the lowest L5/S1 compression force, more than 2 layers produced a lower abdominal angle and higher chest angle compared than 1 layer; however, the abdominal and chest angles measured were almost identical to those measured in LSBs with more than 2 layers. Therefore, a thickness of 2 layers is sufficient to restrict the abdominal angle, and the bending stiffness of LSB texture more than 2 layers does not affect the working posture. Conversely, LSB width affects the working posture and determines the L5/S1 compression force; hence, the optimum design of the width is significant for the physical load reduction of low back.

Perceived abdominal discomfort is influenced by both the width and the thickness of the LSB. Wider LSBs have larger contact areas and restrict abdominal and pelvic excursions. It is also harder to bend when wearing an LSB with more layers, as higher pressures will act on the trunk during bending. Thus, as LSBs become wider and more layered, perceived discomfort increases. The use of LSBs increases the perceived difficulty of a task compared to the no-LSB condition, because it is more difficult to bend the segments while using an LSB. Moreover, the greater width increases the excursion restriction of the segments and thereby increases the difficulty of the task.

The optimum solutions that minimize the L5/S1 compression force and perceived abdominal discomfort correspond with each other, whereas that for the difficulty of the task is different. Therefore, a trade-off is found between the perceived task difficulty and the other indicators. The L5/S1 compression force was selected as the indicator representing the 2 corresponding indicators because it objective, and the Pareto front of the compression force and task difficulty was obtained (Fig. 8). The Pareto front consists of 3 Pareto optimum solutions: 60 mm, 2 layers; 60 mm, 3 layers; and 106 mm, 1 layer. The edges of the Pareto front are the optimum solution of each objective function. The intermediate Pareto solution (60 mm, 3 layers) produces an almost identical L5/S1 compression force and the same difficulty score as the optimum solutions of each objective function. In addition, the perceived discomfort score obtained with the intermediate Pareto solution is 2.93, which is almost the same as the optimum solution of perceived discomfort. Therefore, we conclude that the 60-mm-wide, 3-layer LSB is the most effective in simultaneously reducing the L5/S1 compression force, perceived abdominal discomfort, and perceived difficulty of the task.
5. Conclusions

In this study, we investigated the effects of LSB use on reduction of the physical workload of the low back. The angles of each segment were measured during a bandage-wrapping task using LSBs of different widths and thicknesses. Three indicators were used to evaluate the effects of LSBs: the estimated L5/S1 compression force, perceived abdominal discomfort, and perceived difficulty of the bandage-wrapping task. The major findings are as follows:

1. The use of an LSB decreases the abdominal angle and increases the chest and pelvic angles. This change in angles decreases the distance between the center of gravity of the trunk segments and the L5/S1 disc, thereby reducing the L5/S1 compression force. That is, the use of an LSB reduces the physical workload of the low back by restricting abdominal excursion.

2. The width of the LSB significantly affects the L5/S1 compression force, perceived discomfort, and perceived difficulty of the task; wider LSBs worsen these indicators. LSB thickness significantly affects perceived abdominal discomfort; thicker LSBs (abdominal belt) increase perceived discomfort.

3. The optimum LSB parameters identified in this study reduce the L5/S1 compression force by approximately 8.2% (153 N) compared with the no-LSB condition.

4. The optimum LSB parameters for perceived task difficulty did not correspond with the other indicators. However, \((w, t) = (60 \text{ mm, } 3 \text{ layers})\), which is one of the Pareto optimal solutions, yields almost the same values as the optimum solutions of each indicator. Therefore, the LSB with 60 mm width and 3 layers is the most effective in reducing the workload of the low back during a task involving trunk flexion.
It should be noted that our study has some limitations. The experiments were performed using healthy male subjects; thus, the influence of gender and LBP symptoms should be investigated. It is possible that the optimum LSB parameters are affected by user characteristics, such as gender, body dimensions, age, and LBP symptoms. Therefore, the influences of these characteristics should be investigated when optimizing the LSB parameters. However, it is actually difficult to conduct a complete experiment with considering all of the potential characteristics. Thus, this experiment was derived from only healthy Japanese male subjects because it was easy to ask them to be the subjects. As the next step of this study, user characteristics will be included in the experimental factors; and optimum LSBs for each user characteristic will be determined. In addition, the effects of task type and duration should be also investigated.

Appendix. Radial Basis Function Networks

The RBF network (Orr, 2015) is a type of neural network that yields a response surface via a superposition of basis functions. The output of the RBF network is given by

\[ O(x) = \sum_{j=1}^{m} w_j h_j(x) \]  \hspace{1cm} (A.1)

where \( x = \{x_1, x_2, \ldots, x_n\}^T \) is a design variable vector, \( n \) is the number of design variables, \( w_j \) is the weight for \( h_j(x) \), and \( m \) is the number of training data. The RBF \( h_j(x) \) is given by

\[ h_j(x) = \exp \left( -\frac{\|x - c_j\|^2}{r_j^2} \right) \]  \hspace{1cm} (A.2)

where \( c_j \) and \( r_j \) are the center and radius of the \( j \)-th basis, respectively. In this study, \( r_j \) is given by the following equation (Kitayama and Yamazaki, 2011):

\[ r_j = \frac{d_{j,\text{max}}}{\sqrt{n} \sqrt{m-1}} \]  \hspace{1cm} (A.3)

where \( d_{j,\text{max}} \) denotes the maximum distance between the \( j \)-th training data and another training data in the training set. Learning by the RBF network involves assigning appropriate weights for each basis and is identical to energy minimization of the RBF network. The energy of the RBF network is given by

\[ E = \sum_{i=1}^{m} \|y_i - O(x_i)\|^2 + \sum_{j=1}^{m} \lambda_j w_j^2 \]  \hspace{1cm} (A.4)

where \( y_i \) is the training data at the sampling point \( x_i = \{x_{i1}, x_{i2}, \ldots, x_{in}\}^T \), and \( \lambda_j \) is a regularization parameter whose value is 0.01 in this study (Nakayama, et al., 2002). The optimal weight vector \( w = \{w_1, w_2, \ldots, w_m\}^T \) is given by

\[ w = (H^T H + \Lambda)^{-1} H^T y \]  \hspace{1cm} (A.5)

where \( H, \Lambda, \) and \( y \) are given by

\[ H = \begin{bmatrix} h_1(x_1) & h_2(x_1) & \cdots & h_n(x_1) \\ h_1(x_2) & h_2(x_2) & \cdots & h_n(x_2) \\ \vdots & \vdots & \ddots & \vdots \\ h_1(x_p) & h_2(x_p) & \cdots & h_n(x_p) \end{bmatrix} \]  \hspace{1cm} (A.6)
The results are obtained by calculating the inverse matrix. Therefore, the RBF network can be evaluated quickly, and additional analysis can be easily conducted when new data sets are added.

References

Calmels, P., Queneau, P., Hamonet, C., Le Pen, C., Maurel, F., Lerouvreur, C. and Thoumie, P., Effectiveness of a lumbar belt in subacute low back pain: an open, multicentric, and randomized clinical study, Spine, Vol.34, No.3 (2009), pp.215–220.

Chaffin, D.B., Andersson, G.B.J. and Martin, B.J., Occupational Biomechanics, Fourth ed. (2006), pp.37–160, Wiley.

Cholewicki, J., Lee, A.S., Peter Reeves, N. and Morrisette, D.C., Comparison of trunk stiffness provided by different design characteristics of lumbosacral orthoses, Clinical Biomechanics, Vol.25, No.2 (2010), pp.110–114.

Dillingham, T.R., Lumbar supports for prevention of low back pain in the workplace, Journal of the American Medical Association, Vol.279, No.22 (1998), pp.1826–1828.

Grew, N.D. and Deane, G., The physical effect of lumbar spinal supports, Prosthetics and Orthotics International, Vol.6, No.2 (1982), pp.79–87.

Jellem, P., Bierma-Zeinstra, S.M., van Poppel, M.N., Bernsen, R.M. and Koes, B.W., Feasibility of lumbar supports for home care workers with low back pain, Occupational Medicine, Vol.52, No.6 (2002), pp.317–323.

Jin, R., Chen, W. and Simpson, T.W., Comparative studies of metamodeling techniques under multiple modeling criteria, Structural and Multidisciplinary Optimization, Vol.23, No.1 (2001), pp.1–13.

Kitayama, S. and Yamazaki, K., Simple estimate of the width in Gaussian kernel with adaptive scaling technique, Applied Soft Computing, Vol.11, No.8 (2011), pp.4726–4737.

Kokubo, Y., Maezawa, Y., Furusawa, N., Uchida, K. and Baba, H., Management and prevention of low back pain in nursing personal: report of questionnaire analysis, The Journal of Japanese Society of Lumbar Spine Disorders, Vol.6, No.1 (2000), pp.52–55 (in Japanese).

Larivière, C., Caron, J.M., Preuss, R. and Mecheri, H., The effect of different lumbar belt designs on the lumbopelvic rhythm in healthy subjects, BMC musculoskeletal disorders, Vol.15, No.307 (2014), DOI: 10.1186/1471-2474-15-307.

Ministry of Health, Labour and Welfare in Japan, The 12th Occupational Safety & Health Program (online), available from <http://www.mhlw.go.jp/new-info/kobetu/roudou/gyousei/kantoku/dl/040330-8.pdf>, (accessed on 20 October, 2015).

Nakayama, H., Arakawa, M. and Sasaki, R., Simulation-based optimization using computation intelligence, Optimization and Engineering, Vol.3, No.2 (2002), pp.201–214.

NIOSH (National Institute for Occupational Safety and Health), Musculoskeletal Disorders and Workplace Factors, A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back (online), available from <http://www.cdc.gov/niosh/docs/97-141/> , (accessed on 20 October, 2015).

Nishijima, U., Habatake, Y., Hatano, H., Yamada, H., Iwasaki, T., Chihara, T. and Seo, A., Effect of lumbar support belt on working posture, The Japanese Journal of Ergonomics, Vol.51, No.2 (2015), pp.115–122 (in Japanese).

Orr, M. J. L., Introduction to radial basis function networks (online), available from <http://anc.ed.ac.uk/rbf/papers/intro.ps.gz>, (accessed on 20 October, 2015).

Roelofs, P.D., Bierma-Zeinstra, S.M., van Poppel, M.N., Jellem, P., Willemsen, S.P., van Tulder, M.W., van Mechelen, W. and Koes, B.W., Lumbar supports to prevent recurrent low back pain among home care workers, Annals of International Medicine, Vol.147, No.10 (2007), pp.685–692.
Roelofs, P.D., Bierma-Zeinstra, S.M., van Poppel, M.N., van Mechelen, W., Koes, B.W. and van Tulder, M.W., Cost-effectiveness of lumbar supports for home care workers with recurrent low back pain: an economic evaluation alongside a randomized-controlled trial, Spine, Vol.35, No.26 (2010), pp.E1619–E1626.

Smedley, J., Egger, P., Cooper, C. and Coggan, D., Prospective cohort study of predictors of incident low back pain in nurses, British Medical Journal, Vol.314, No.7089 (1997), pp.1225–1228.

Thuomie, P., Drape, J.L., Aymard, C. and Bedoiseau, M., Effects of a lumbar support on spine posture and motion assessed by electrogoniometer and continuous recording, Clinical Biomechanics, Vol.13, No.1 (1998), pp.18–26.

van Duijvenbode, I., Jelliema, P., van Poppel, M. and van Tulder, M.W., Lumbar supports for prevention and treatment of low back pain, Cochrane Database of Systematic Reviews, (2008), DOI: 10.1002/14651858.CD001823.pub3.

van Poppel, M.N., de Looze, M.P., Koes, B.W., Smid, T. and Bouter, L.M., Mechanisms of action of lumbar supports: a systematic review, Spine, Vol.25, No.16 (2000), pp.2103–2113.

van Poppel, M.N., Hoofman, W.E. and Koes, B.W., An update of a systematic review of controlled clinical trials on the primary prevention of back pain at the workplace, Occupational Medicine, Vol.54, No.5 (2004). pp.345–352.

Wada, O. Handbook of Occupational Health III, Low Back Pain (2006), pp.1–22, The Occupational Health Promotion Foundation (in Japanese).