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# The Effects of Experience and the Presence of a Scaffold Handrail on Postural and Spinal Stability in Construction Workers

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# The Effects of Experience and the Presence of a Scaffold Handrail on Postural and Spinal Stability in Construction Workers

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*The goal of this study was to quantify the effect of experience and handrail presence on trunk muscle activities, rotational spinal stiffness and postural stability of construction workers. We evaluated spinal stability, and objective and subjective postural stability in 4 expert and 4 novice construction workers who were performing a manual task in a standing position on a scaffold, with and without a safety handrail. Center of pressure was computed using measurements taken with insole pressure transducers. Muscle activity was monitored using surface electrodes placed on 8 trunk muscles that predicted active trunk rotational stiffness. Standard deviations of the center of pressure, back muscle activity and spinal stiffness were greater in novices and in the absence of a handrail. We infer that the risk of a fall due to postural and spinal instability may be greater with a lower level of experience and in the absence of a safety handrail.*

fall    low back pain    postural stability    lumbar stability    construction    injury



## 1. INTRODUCTION

Since the 1970s, adherence to safety standards and guidelines has become more challenging due to the high speed of growth in developing countries, particularly in South Korea. The development of construction and engineering technology has increased the amount of large-scale construction work, e.g., skyscrapers, taking place; because of this increase, the types of safety accidents that can occur on construction sites have become more diverse [1]. According to Cattledge, Schneiderman, Stanevich, et al., 60% of workers' compensation claimants had been employed for 2 years or less by the company for which they worked at the time of the fall/injury; 26% had been employed for 6 months or less [2]. Approximately 63% of the 182 claimants in their study had received some type of fall protection training prior to the accident. Ladders and scaffolds were involved in 50% of all falls [2]. Using proportionate mortality rates (PMR) for the USA as a comparison population, statistically significant, elevated risks (95% confidence intervals, CI) were calculated for falls ($n = 259$, PMR = 3.57, CI [3.15, 4.03] for unionized construction ironworkers [3].

Back pain is a frequent complaint of workers on construction sites [4, 5, 6, 7, 8]. Back pain patients tend to have poor balance [9], which causes a vicious cycle for those construction workers that may suffer from low back pain as they may be more vulnerable to accidents in the workplace due to loss of balance [10], or a slip or fall [11, 12, 13, 14]. According to the U.S. Bureau of Labor Statistics, fatal injuries in the private construction sector declined by 16% in 2009 due to lower total work hours, yet the construction industry still accounted for about half of the 617 fall fatalities in the USA that year [15]. Overexertion and fall injuries constitute the largest categories of injuries among scaffold workers [10].

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Postural stability has been studied using force plates in the laboratory and using pressure-sensitive insoles that allow more freedom of movement to subjects being studied in laboratory or field settings. A number of studies have used center of pressure (COP), which is a useful means of assessing postural stability and evaluating loss of balance and vertigo when the subject is standing straight [16, 17, 18]. Furthermore, when measuring postural stability, assessing the COP produces more accurate results than does assessing center of gravity (COG) or center of mass (COM) [19, 20]. Anterior–posterior (A/P) and medial–lateral (M/L) COP movement can be used for the direct measurement of postural stability [21]; insole pressure may also be a reliable measure of postural stability [22, 23, 24, 25]. Several researchers have studied myoelectrical activity and postural stability under conditions of various sensory alterations (open or closed eyes, soft or solid surfaces, narrow or wide areas of support, and stable or perturbed surfaces) in musculoskeletal and neurological patients, with or without dual tasking [26, 27, 28, 29, 30, 31, 32, 33, 34].

Fall prevention strategies for elevated working surfaces should include installing handrails and providing adequate training, specifically on-the-job apprenticeships [12, 35, 37]. The biomechanical mechanisms linking the level of experience and installment of handrails to loss of balance and fall are far from clear; however, positive safety-related changes to the working environment can significantly affect worker psychological states and biomechanical responses in terms of muscle recruitment, i.e., neural strategy [38, 39].

We studied the effects of worker experience and the presence of a handrail on both experienced and novice workers performing identical tasks; in this case, chipping concrete from a wall while standing on a scaffold. Our hypotheses were (a) absence of handrails will significantly affect objective and subjective postural stability, and will increase trunk rotational stiffness through greater co-activation of the trunk muscles; (b) worker experience level will significantly affect postural stability, trunk muscle recruitment and rotational trunk stiffness while performing a chipping task on a scaffold; and (c) the presence of a handrail will affect novice workers differently than expert ones.

Hence, the purpose of this study was to assess whether measures of postural stability, trunk muscle activity, rotational spinal stability and subjective difficulty for postural stability were affected by level of experience (expert or novice) and safety handrail (presence or absence). Multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) were used to test the aforementioned hypotheses using a repeated-measures design with experience as the between-subject effect, and handrail presence as the within-subject effect. The confidence level for statistical significance was set at $\alpha = .05$.

## 2. METHODS

The subjects in this study were 4 novice and 4 expert volunteers who had worked on construction sites using scaffold frames. The experts were operationally defined as having over 10 years of experience in the construction industry. All subjects were right-hand and right-foot dominant, and none had previously experienced a fall or back pain in the past 12 months that restricted their activities [9]. The two groups were not different with respect to their height and weight; however, the experts were 9.3 years older than the novices ($p < .05$), with 15 years more experience on the job ($p < .05$). Table 1 shows mean subject demographics.

Those subjects who met the study inclusion criteria received information regarding the purpose and methods of the study and signed a copy of the consent form that was approved by the institutional review board.

To ensure identical assembly and configuration of the scaffold frames used in this study, we used scaffold frames with a floor height of 1.80 m that could be mounted with safety handrails (Figure 1). The dimensions of the scaffold frame were 1.20 × 1.80 × 1.80 m (width × depth × height), and the safety handrails were mounted 0.97 m above the scaffold floor.

To assess postural stability, standard deviations of the COP in the A/P and M/L directions beneath

**TABLE 1. Mean (*SD*) Subject Demographics**

| Demographic | Novice (*n* = 4) | Expert (*n* = 4) | Mann–Whitney *U* |
|---|---|---|---|
| Age (years) | 27.0 (3.6) | 36.3 (7.0) | 0.00* |
| Experience (years) | 1.3 (1.0) | 16.3 (1.0) | 0.00* |
| Weight (kg) | 70 (5.1) | 68 (8.5) | 7.00[a] |
| Height (cm) | 172.3 (6.2) | 173 (2.1) | 7.50[a] |

*Notes.* *$p < .05$; a = nonsignificant.

(a)  (b) 

**Figure 1. Scaffold frame (a) without a safety handrail, (b) with a safety handrail.**



each foot were measured with wearable pressure-measurement insoles using F-Scan (Tekscan, USA). An eight-channel electromyogram (EMG) system, ME-6000T (Mega Win, Finland), was used to monitor the EMG activity of eight trunk muscles to estimate their overall contributions to rotational spinal stiffness in each of the following cardinal planes: sagittal, coronal and transverse at L4/L5. Rotational spine stiffness was computed using the muscle activity of the eight trunk muscles as a measure of spinal stability. This computation was based on Rashedi, Khalaf and Reza's theoretical work [40]; spinal stability has also been related to trunk muscle stiffness by Rashedi et al. using the earlier contributions of Bergmark [41] that related muscle force to muscle stiffness. All experiments were recorded on a 6-mm digital camcorder.

In this experiment, a 2 × 2 mixed-factors design was used to examine the effects of the presence of a safety handrail and worker experience on biomechanical measures of normalized muscle activity, and objective and subjective postural and spinal stability. Independent variables for the experiment included experience (between-subjects factor) and the presence of a safety handrail. Our dependent variables were the objective measures of postural stability (*SD* of the COP in the A/P and M/L directions), subjective difficulty in maintaining postural balance, normalized muscle activity and the three rotational spinal stiffness variables at L4/L5.

The study objectives and procedure were explained to the subjects before the experiment. To evaluate spinal stability, EMG electrodes were bilaterally attached to muscles related to spinal stability: rectus abdominis, external obilquus, latissimus dorsi, and erector spinae [42, 43]. To normalize EMG signals, we used a fixture that could stabilize the lower body to accommodate trunk isometric maximum voluntary contraction (MVC) in different directions to obtain the maximum muscle activation of each of the eight trunk muscles, as suggested by previous studies [43]. EMG signals were sampled at 1000 Hz, and a band-pass filter was used to obtain signals between 20 to 500 Hz. The EMG was processed and normalized by the maximum values in accordance with an EMG-driven model [43], which was in turn incorporated into Rashedi et al.'s model [40] to estimate muscle stiffness and the total muscle contribution of rotational spinal stiffness at L4/L5, as detailed in the next section.

Following measurement of the subjects' MVCs, F-Scan insole sensors were placed inside the construction safety shoes. After all measuring equipment was completely installed, the subjects stood still on the ground for 3 min while postural stability and muscle activity were measured. The subjects then performed a manual chipping task on a concrete wall while standing on the scaffold, with and without a handrail, for 3 min per trial. To prevent fatigue, a 5-min break was provided between each experimental condition and a Latin square design was used to reduce carry-over effects.

Postural stability was evaluated using insole pressure measurements for 3 min in the presence or absence of a safety handrail while performing the manual chipping task. When the task was completed, the subjective difficulty of maintaining postural balance was assessed by the subject using Borg's 10-point scale, where 0 = *nothing at all*, 10 = *very, very hard* [44].

### 2.1. Postural Stability Calculation

To assess an individual's postural stability, the total force and COP estimated for each foot were combined based on the algorithm defined by Schepers, van Asseldonk, Buurke, et al. [45] to obtain the overall COP in A/P and M/L. The *SD* of COP were calculated based on Salavati, Hadian, Mazaheri, et al. [31] and Kitabayashi, Demura, Noda, et al. [46] to quantify the performance variability of postural balance.

### 2.2. Spinal Stability Calculation

To calculate spinal stability, normalized EMG signals from each muscle were used to compute their contributions to rotational muscle spinal stiffness, $K_j$, as calculated using the following relation from Rashedi et al. [40]:

$$K_j = \sum_{i=1}^{8} d_{ij}^2 k_i, \qquad (1)$$

where $k_i$ = $i$th muscle stiffness, $d_{ij}$ = $i$th muscle moment arm in $j$th plane. Based on Bergmark [41] and Sparto, Parnianpour, Marras, et al. [43], $k_i$ and force $F_i$ are found to be

$$k_i = \mathrm{q}\frac{F_i}{l_i} \text{ and } F_i = G \cdot PCSA_i \cdot NEMG_i, \qquad (2)$$

respectively, where q = proportionality constant; $l_i$ = length of $i$th muscle; $G$ = maximum allowable muscle stress; $PCSA_i$ = physiological cross-sectional area of $i$th muscle; $NEMG_i$ = normalized EMG of $i$th muscle. Upon collecting terms, $K_j$ can be written as

$$K_j = \mathrm{q} \cdot G \sum_{i=1}^{8} \frac{PCSA_i}{l_i} \cdot NEMG_i \cdot d_{ij}^2, \qquad (3)$$

where q = proportionality constant; $G$ = maximum allowable muscle stress; $PCSA_i$ = physiological cross-sectional area of $i$th muscle; $l_i$ = length of $i$th muscle; $NEMG_i$ = normalized EMG of $i$th muscle; $d_{ij}$ = $i$th muscle moment arm in $j$th plane.

Since we did not estimate q and $G$ without loss of generality, we calculated scaled rotational muscle spinal stiffness in each cardinal plane, $\tilde{K}_j$ as follows:

$$\tilde{K}_j = \frac{K_j}{\mathrm{q} \cdot G} = \sum_{i=1}^{8} \frac{PCSA_i}{l_i} \cdot NEMG_i \cdot d_{ij}^2, \qquad (4)$$

where $K_j$ = rotational muscle spinal stiffness; q = proportionality constant; $G$ = maximum allowable muscle stress; $PCSA_i$ = physiological cross-sectional area of $i$th muscle; $l_i$ = length of $i$th muscle; $NEMG_i$ = normalized EMG of $i$th muscle; $d_{ij}$ = $i$th muscle moment arm in $j$th plane.

### 2.3. Analysis

MANOVA and ANOVA were used with a repeated-measures design to investigate the main and interaction effects of the independent variables (presence of a safety handrail and experience) on each of the dependent variables (objective and subjective measures of postural stability and spinal stability). Multiple comparisons of means were performed using post hoc analysis; Bonferroni correction was also applied. Statistical analyses were performed using SPSS version 18. Levene's test for homogeneity of variance and Kolmogorov–Smirnov test were used to check the two assumptions required for ANOVA, which were both satisfied.

## 3. RESULTS

Table 2 reports the results of MANOVA and ANOVA on all postural and spinal stability measures used to assess the main and interaction effects of experience and handrail presence.

### 3.1. Posture Stability

The MANOVA results demonstrated significant differences in COP *SD* due to the presence of a handrail ($F(3, 4) = 90.5$, $p < .05$) and experience ($F(3, 4) = 6.81$, $p < .05$; Table 2). Based on ANOVA results, the main effects of handrail and experience were statistically significant for both the A/P and M/L directions ($p < .05$; Table 2). The ANOVA results indicated higher COP *SD* for novices than experts and in the absence of a handrail (Figure 2).

### 3.2. Subjective Difficulty Maintaining Postural Stability

Figure 3 shows participants' responses to Borg's scale regarding subjective difficulty in maintaining postural balance under different conditions. The ANOVA interaction effect

**TABLE 2. MANOVA and ANOVA (*F* Values) Assessing Postural Stability, Spinal Stability, Muscle Activity and Subjective Difficulty for Postural Stability**

| Postural Stability | Experience | Handrail | Handrail × Experience |
|---|---|---|---|
| MANOVA for all COP *SD* | 6.813* | 90.490* | 4.872[a] |
| ANOVA for COP *SD* | | | |
| anterior–posterior | 7.287* | 6.474* | 5.474[a] |
| medial–lateral | 7.932* | 20.190** | 5.048[a] |
| Subjective difficulty for postural stability (ANOVA) | | | |
| postural difficulty for balance | 19.746** | 21.000** | 10.714* |
| Muscle activity | | | |
| MANOVA for all muscles | 18.839* | 587.412** | 1.770[a] |
| ANOVA for individual muscles | | | |
| L rectus abdominis | 20.873** | 11.626* | 0.001[a] |
| R rectus abdominis | 11.077* | 13.836** | 0.134 |
| L external obliquus | 24.563** | 7.785* | 5.050[a] |
| R external obliquus | 23.300** | 8.648* | 2.892 |
| L latissimus dorsi | 7.001* | 10.250* | 3.587[a] |
| R latissimus dorsi | 13.988** | 6.959* | 1.651[a] |
| L erector spinae | 9.392* | 15.792** | 0.035[a] |
| R erector spinae | 10.786* | 12.501* | 6.225* |
| Spinal stability (stiffness) | | | |
| MANOVA for all stiffness | 11.967* | 36.085** | 1.652[a] |
| ANOVA for all stiffness | | | |
| sagittal plane | 0.511[a] | 13.191* | 4.013[a] |
| coronal plane | 7.825* | 25.009** | 0.802[a] |
| transverse plane | 0.676[a] | 21.813** | 0.977[a] |

*Notes.* *$p < .05$, **$p < .01$, a = nonsignificant; MANOVA = multivariate analysis of variance, ANOVA = analysis of variance, L = left, R = right.

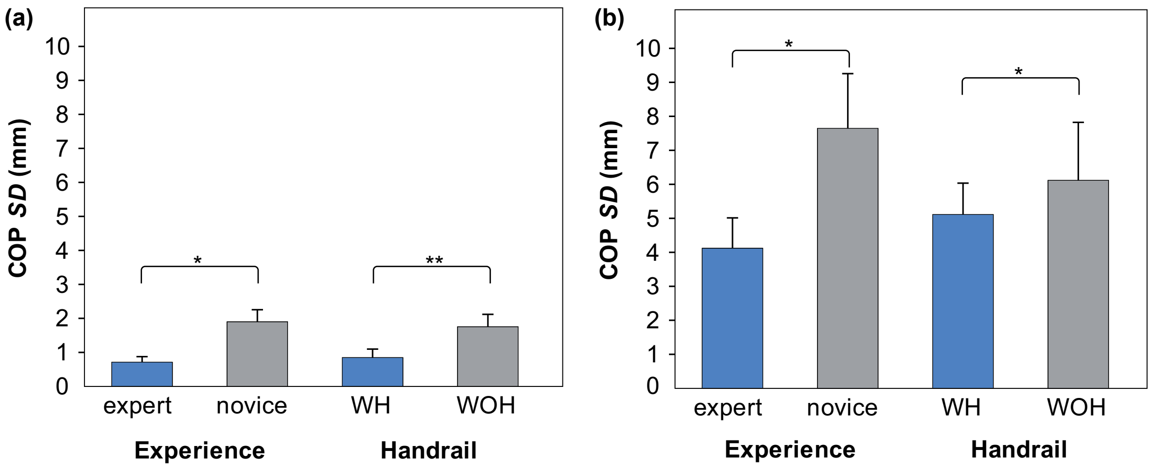


**Figure 2. Main effects of experience and a handrail on center of pressure (COP) *SD* (a measure of postural stability) in (a) anterior–posterior and (b) medial–lateral direction.** *Notes.* *$p < .05$, **$p < .01$; WH = with a handrail, WOH = without a handrail; error bars denote *SD*.

revealed a significantly greater increase in perceived difficulty for novice workers when a handrail was not present ($F(1, 6) = 10.7$, $p < .01$; Table 2).

### 3.3. Muscle Activity and Spinal Stability

The MANOVA results in Table 2 indicate that the main effects of a handrail and experience significantly affected muscle activity ($p < .05$). The ANOVA results indicate that the novices had higher trunk muscle activity than the experts, and the presence of a handrail reduced activity in all trunk muscles ($p < .05$; Figure 4 and Table 2). Although the right erector spinae showed statistically significant interaction effects ($F(1, 6) = 6.23$, $p < .05$), illustrating a slightly greater increase in activity (0.23%) in the novices in the absence of a handrail, the functional significance of such a small increase is negligible.

The MANOVA results revealed significant differences in rotational spinal stiffness based on muscle stiffness according to both experience ($F(3, 4) = 11.97$, $p < .05$) and the presence of a handrail ($F(3, 4) = 36.08$, $p < .01$; Table 2). The ANOVA results demonstrated higher rotational trunk stiffness in the absence of a handrail in all three cardinal planes ($p < .05$; Figure 5, Table 2). The novices had higher rotational stiffness than the experts, although only coronal stiffness reached a level of statistical significance ($F(1, 6) = 7.83$, $p < .05$).

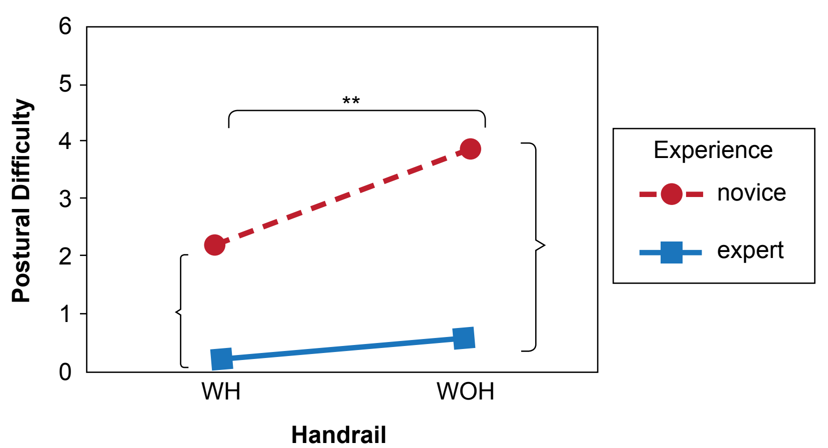


**Figure 3. Interaction effects of experience and a handrail on subjective difficulty of postural stability.** *Notes.* *$p < .05$, **$p < .01$; WH = with a handrail, WOH = without a handrail; 0 = *nothing at all*, 1 = *very light*, 2 = *fairly light*, 3 = *moderate*, 4 = *somewhat hard*, 5 = *hard*, 6 = *very hard*.

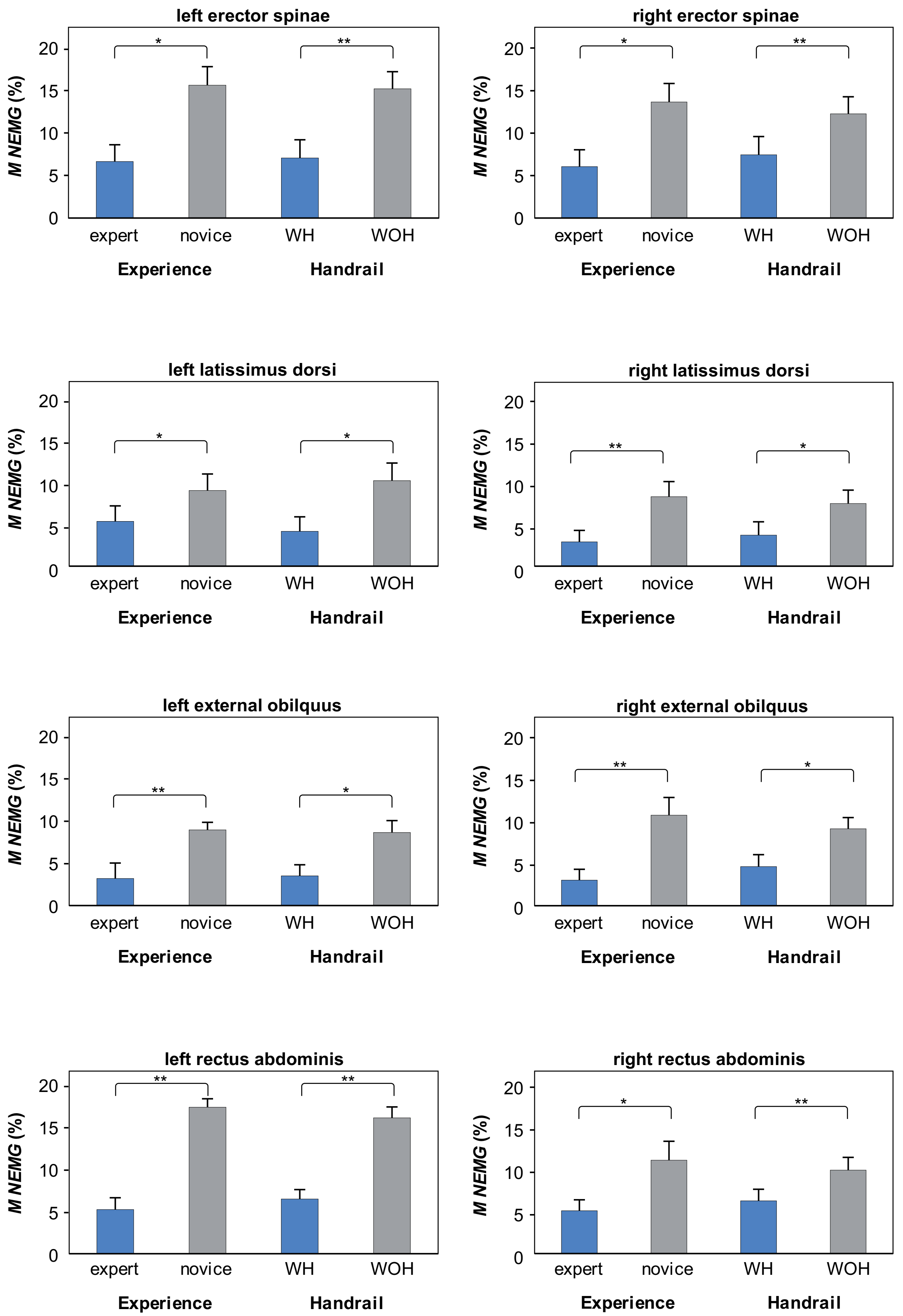


**Figure 4. Normalized muscle activity of each trunk muscle using scaffolds with (WH) or without a handrail (WOH), between experts and novice construction workers during manual chipping task.**
*Notes.* *$p < .05$, **$p < .01$; *NEMG* = normalized electromyogram; error bars denote *SD.*

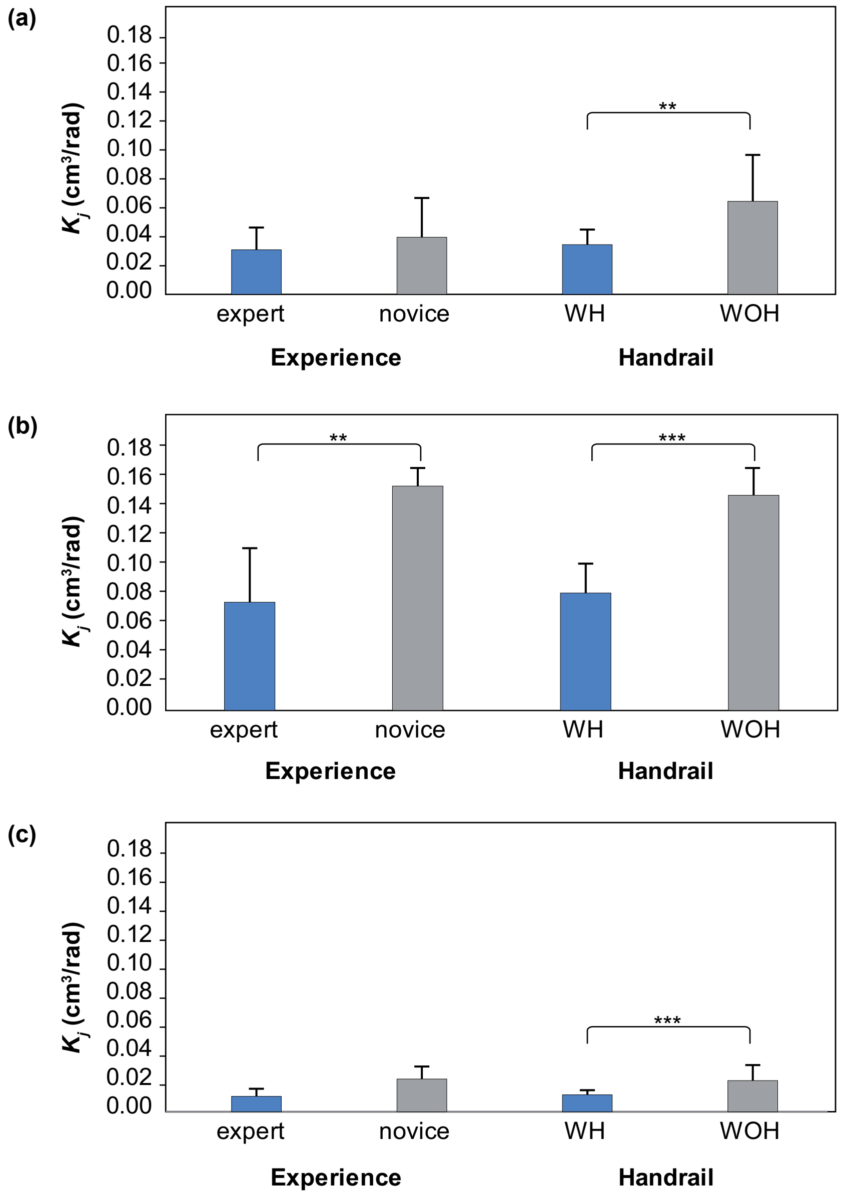


**Figure 5. Spine rotational stiffness in (a) sagittal, (b) coronal and (c) transverse planes due to trunk muscle activity using scaffolds with (WH) or without a handrail (WOH), between expert and novice construction workers during manual chipping task.** *Notes.* $*p < .05$, $**p < .01$; error bars denote *SD*.

## 4. DISCUSSION

Both novice and expert workers appear to employ greater trunk muscle activity to improve spinal stability when working on a scaffold without a handrail (Figures 4–5). This increased muscle activity may be due to psychological anxiety associated with the potential of falling from an elevated height. The greater increase in perceived difficulty by novices to maintain their balance (Table 2, Figure 3) is in agreement with previous studies that have found a greater perceived risk of working on scaffolds [36, 47]. Novices were found to have more muscle activity than experts, which suggests that novices used more active stiffness in their back muscles than experts to maintain their balance [48]. When more back muscles are used to maintain stability, the worker may become fatigued more easily [49]; increased use of back muscles may even lead to back pain due to increased pressure on the spine [3, 40, 48]. More quantitative studies are necessary to evaluate the forces generated on the spine before the full implication of higher observed activations can be assessed [38, 39, 43].

There is clear evidence that postural sway can be sensed by the mechanoreceptors of the foot, and sensory information is then transmitted to the spinal cord to co-ordinate the activation of trunk and leg muscles to maintain balance [50, 51, 52]. In fact, interesting studies have shown that providing feedback of COP location can decrease postural sway and enhance postural stability [53]. The training of novice workers can hence be augmented by performing simulated work at the elevated height. The fear of falling can be reduced by increasing worker confidence and using a reduced COP *SD* as an objective biofeedback measure of enhanced postural stability skills.

Scaffolds are one of the most common items cited by safety inspectors, and the Occupational Safety and Health Administration (OSHA) Fall Protection Standard for Construction (Subpart M of 29 CFR 1926) requires the use of fall protection devices, such as a harness, when any construction employee is working on a surface higher than 1.80 m from the ground, which corresponds to the height of the first-floor scaffold in this study [54]. OSHA officials suggest that this trigger height saves up to 80 lives per year and prevents over 56 000 injuries. This regulation is controversial because compliance is costly (~300 million USD in the USA) and smaller companies struggle to self-enforce the regulations [54]. The results of this study provide biomechanical evidence that working at an elevated height affects psychological states, which have biomechanical consequences, i.e., more perceived difficulty maintaining postural balance and higher trunk muscle activation (Figures 3–5). Hence, additional attention must be given to preventive measures, such as installing handrails and providing harnesses, which provide a psychological sense of security and safety. Stricter adherence to handrail safety regulations must be enforced.

A greater number of years of experience in the construction industry reduced the *SD* of COP and lowered the subjective difficulty of maintaining balance. These results agree with other data that suggest that novice construction workers are more vulnerable to accidents on construction sites [6, 7, 11, 36, 55]. We feel that this preliminary result justifies a larger field study to further delineate the mechanisms by which experience affects postural stability and trunk muscle activity.

We recommend the use of engineering reinforcements to increase scaffold rigidity and reduce associated risk factors. The effectiveness of this intervention could be investigated using the methodology presented in this paper.

Safety handrails are recommended to avoid postural instability that may contribute to falls from scaffolds. An elevated prevalence of low-back pain has been observed in construction workers [4, 5, 6, 7, 8], and the lower postural stability of low-back pain patients under challenging sensory and dual task studies [30, 31] may explain the larger number of falls from scaffolds in the construction industry.

The limitations of our results should be considered. Even though the multitude of tests we performed showed strong statistical significance and indicated adequate power, which was verified by direct assessment of power using the MANOVA procedure in SPSS, we recommend that future studies use a larger study population. The median (minimum to maximum) power computed for the main effects of a handrail and experience (Table 2) were .86 (.59–1) and .80 (.10–.98), respectively. This is possible due to the large effect sizes of the independent variables; the effect sizes as measured by median $\eta^2$ (partial $\eta^2$) of all tests reported in Table 2 were .69 and .67 for experience and a handrail, respectively. In addition, since homogeneity variance and normal distribution requirements of ANOVA were satisfied we used this procedure rather than nonparametric statistics.

The mathematical model included averaged values from the literature for muscle moment arms and assumed a linear relation between muscle force and muscle stiffness [40]. Due to low levels of muscle activity, the linearity between muscle force and muscle stiffness most likely holds [41] and the individualized muscle moment arms should not alter the rotational spinal stiffness response to each of the independent variables as higher co-activation (measured by normalized EMG) yields higher stiffness. More accurate stability analysis taking equilibrium at all levels of the spine using individualized muscle anatomical characteristics should be conducted to mitigate the aforementioned limitations [56].

The variability of task demand in this field study has not been quantified. It was assumed that with a long test duration and random process of chipping concrete from a wall, the demands should be quite similar across the testing conditions. Lastly, the subjects were not matched by age as the experts were significantly older than the novices ($U = 0.00$, $p < .05$). Arguably, the observed data trend should not be affected, as age can only deteriorate postural balance [27]. Given the fact that the experts showed better postural stability both subjectively and objectively, we expect that matching the ages of the two groups would only increase the observed differences between the two groups.

Based on the results of this study, we recommend the installment of safety handrails and the practical training of novice workers that simulates the postural stability challenges presented while working on scaffolds and at elevated heights.

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