ROLES OF CUTANEOUS SENSATION AND GLOVES WITH DIFFERENT COEFFICIENTS OF FRICTION ON FALL RECOVERY DURING SIMULATED LADDER FALLS

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INTRODUCTION

Falling from a ladder is a common injury among industry workers [1, 2]. Hands are the only means available to arrest a fall once it has been initiated. Knowledge on how people detect and respond to a ladder fall with the upper limb is currently limited. In addition, whether gloves affect the hand's detection and response for a fall is unknown. Such knowledge is necessary to design interventions to reduce ladder fall injuries. The objective of this study was to determine the time course of a fall event (i.e., changes in hand force, rung position, upper limb muscle activities) in response to a sudden upward loading of the rung, simulating a ladder fall. In addition, the effect of gloves with different coefficients of friction (COF) on a person's detection and response time was examined.

METHODS

Thirteen right-handed young adults (9 males and 4 females with the mean age of 25 ± 5 years) with no history of neuromuscular disorders volunteered for this study. Subjects sat on a chair with the non-dominant left hand holding an overhead aluminum rung (3.8 cm in diameter) (Fig 1).

The initial upper limb position was approximately 160° shoulder flexion with no abduction or adduction and 10° elbow flexion. Subjects held the rung with no extra effort at the beginning of a trial. A sudden upward load was applied to the rung at a random time via drop of a weight that was connected to the rung through a cable and pulleys. The weight was set to be each subject's 10% of maximal pull strength. Subjects were instructed to stop the rung from moving up. This rung perturbation trial was repeated three times for each of three glove conditions (polyester glove with COF = 0.33, bare hand with COF = 0.56, and latex glove with COF = 1.1 against aluminum). All subjects were able to stop the rung for all trials.

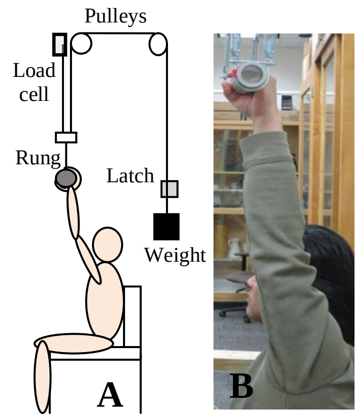

Figure1: A. Arrangement of the rung and weight in the experimental layout. **B.** Upper limb position in the beginning of each trial.

Hand force, rung vertical position, and muscle activities were recorded during each trial. Hand force was recorded using a load cell connected to the rung. The rung's vertical position and the latch opening for a weight drop were recorded using Optotrak 3D Investigator Motion Capture System (NDI, Waterloo, ON, Canada). Muscle activities for flexor digitorum superficialis, flexor carpi ulnaris, extensor digitorum communis, biceps, triceps, deltoid, pectoralis major and latissimus dorsi were recorded using bipolar surface EMG electrodes (Bortec Biomedical Ltd., Calgary, Alberta, Canada). These muscles were selected for their important role in moving and stabilizing the upper limb.

The time course of a typical trial is shown in Fig 2. Times at which (1) hand force started increasing, (2) the rung started moving up, (3) the rung stopped moving, and (4) muscle EMG started increasing were determined relative to the weight drop (Fig 2). The hand force increase was determined to have occurred when the slope of the force curve exceeded 0.030 N/s. The rung movement was determined to have occurred when the velocity of the rung exceeded 0.001 cm/s. The rung was determined to have been stabilized when the rung's velocity reached zero. Increased muscle EMG was determined by visual examination. The earliest EMG increase among the 8 muscles determined the muscle reaction time.
Repeated measures ANOVA determined the differences in mean times for hand force increase,

muscle reaction, rung movement start, and rung stabilization. Four repeated measure ANOVA determined if the within-subject factor of glove affected the times of hand force increase, muscle reaction, rung movement start and stabilization.

RESULTS

A typical time course entailed 1) hand force increase (41 ms after weight drop), followed by 2) muscle reaction (101 ms), 3) vertical rung movement (116 ms), and 4) stabilization of the rung (461 ms) (Table 1) ($p<.05$). The mean times for hand force increase, muscle reaction, and rung movement initiation did not significantly differ by glove ($p>.05$). The mean rung stabilization time significantly varied by glove ($p<.05$).

DISCUSSION

The time course of the simulated fall event indicates that people detected the rung perturbation through the increase in hand force (i.e., rung resisted by the upper limb weight) and then they increased muscle activities. The rung movement (and thus associated joint movement) did not occur until after the muscle activities increased, suggesting that the cutaneous sensation was the cue available for people to react to the perturbation, rather than proprioception.

This muscle reaction time was not dependent on the glove condition, possibly because the cutaneous sensation detecting the skin pressure was not affected by the glove layer. However, the glove condition was important for stabilizing the rung. Specifically, the rung stabilization time decreased with increasing COF glove condition. People took the longest time in stabilizing the rung while wearing the lowest-friction polyester glove, probably because a low-friction condition requires a greater grip force to resist the rung slippage out of the hand, compared to a high-friction condition.

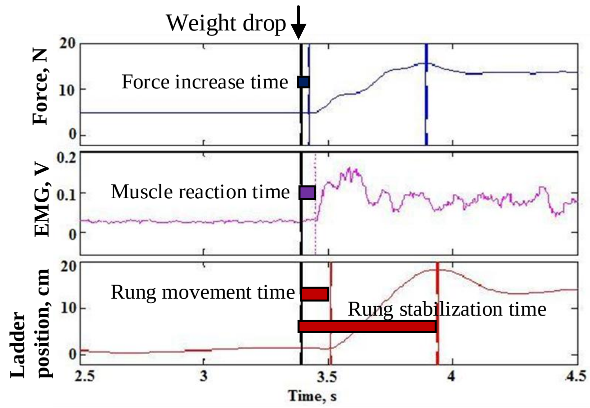

Figure 2: Time course of a simulated ladder fall by a sudden loading of the rung. Hand force (top), flexor carpi ulnaris muscle's RMS EMG (middle), and rung displacement (bottom) are shown.

CONCLUSIONS

The study demonstrated that cutaneous sensation for finger pressure is the first cue available for people to react to a simulated ladder fall. The study also demonstrated that the glove frictional condition can significantly affect a person's ability to stabilize a rung in a timely manner. For functional applications, low-friction gloves such as polyester gloves may hamper a person's ability to recover from a ladder fall and thus may not be advisable.
A future study may determine if enhanced cutaneous sensation such as via stochastic resonance may enable a person to detect and respond to a ladder fall faster. Future studies may also include the vestibular input's contribution to fall detection.

REFERENCES

1. BLS, *Census of fatal occupational injuries summary.*, BLS. 2005: Washington.
2. BLS, *Fatal occupational injuries by event or exposure, 2008-2009*, BLS. 2009.

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Table 1: Mean (SD) times for changes in force, rung position, and muscle activity for the 3 glove conditions

	Polyester glove	Bare hand	Latex glove	*p*-value
Coefficient of friction against aluminum	0.33	0.56	1.1	
Hand force increase time (ms)	34.29 (5.06)	49.48 (10.29)	37.97 (7.23)	>.05
Muscle reaction time (ms)	88.13 (7.46)	111.69 (13.08)	102.10 (5.67)	>.05
Rung movement time (ms)	124.36 (24.28)	116.92 (16.53)	122.82 (19.04)	>.05
Rung stabilization time (ms)	483.97 (77.61)	456.15 (87.6)	455.26 (77.21)	<.05