

# FATIGUE EFFECTS ON SLIP RISK WHILE WEARING FIRE-PROTECTIVE EQUIPMENT

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## INTRODUCTION

In 2006, over 10,000 firefighter injuries resulted due to slips and falls, accounting for approximately 25% of all fireground injuries [1]. Fire-protective equipment has been shown to negatively impair postural balance by increasing sway length and sway area [2].

After experiencing a slip or anticipating a slippery surface, subjects have been shown to alter their gait. Several ways this is accomplished is by reduced stance duration, normalized stride length, and angular foot velocity at heel contact [3]. Additionally, subjects alter their gait by reducing their peak required coefficient of friction (RCOF) after a slip or when anticipating a slippery surface. These changes have been shown to reduce slip risk [3-6].

Fatigue has also been shown to alter gait and slip risk. Specifically, previous research has found that following induced quadriceps fatigue, subjects increased their RCOF, thus increasing their slip risk [4,5]. It was found that this increased risk of slipping may result in a higher incidence of falls due to fatigue [5]. Additionally, studies have shown that postural sway increases after fatigue, leading to increased fall risk [7,8].

It is possible that combining fatigue and fire-protective equipment will result in even greater disturbances in balance and gait. The goal of this study was to determine the effect of fatigue on slip risk while wearing fire-protective equipment.

## METHODS

Six male subjects (mean age  $28.2 \pm 6.4$  years, height  $1.77 \pm 0.06$  m, mass  $83.3 \pm 5.4$  kg), screened for adequate physical abilities, participated in this study. Each wore a heart rate monitor and fire protective gear including: fire resistant pants and

coat, steel toe boots, Nomex hood, heavy gloves, polycarbonate helmet, self-contained breathing apparatus, and facemask.

Subjects, carrying a 6.8 kg bar to mimic an axe, walked at a self-selected pace across a vinyl tile walkway. Ground reaction forces and whole body motion were sampled at 1080 and 120 Hz, respectively. The subjects performed five baseline dry walking trials (BD). Without the subjects' knowledge, a glycerol solution (glycerol-water ratio of 75:25) was applied at the left/leading foot-floor interface, generating an 'unexpected slip'.

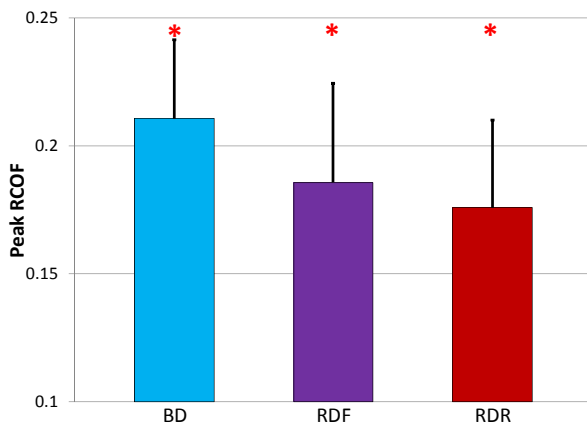
Subjects were then randomized into two groups, fatigue or rest. Subjects in the fatigue group experienced a 20 minute fatigue protocol. Fatigue consisted of carrying the bar up and down two flights of stairs, dragging a 29 kg dummy backwards, performing a 12 lb bucket pull for one minute at 90 bpm, and resting for two minutes. Repetitions were performed for the 20 minute period. All subjects exceeded 85% of age predicted heart rate maximum during the fatiguing period. Following fatigue, subjects performed 10 recovery dry walking trials (RDF). This was followed by an 'unexpected slip' on the 11<sup>th</sup> trial. Subjects then underwent a 20 minute seated rest period. Another 10 recovery dry trials (RDR) and a third slip on the 11<sup>th</sup> trial were collected. Subjects in the rest group underwent the same protocol except they experienced the rest period first and the fatigue period second.

The variable of interest was peak RCOF for BD, RDF and RDR. Peak RCOF was calculated using the ratio of force in the anterior-posterior direction to the normal force. The maximum value during 10-30% of the stance was selected for analysis [6].

A within-subject ANOVA was performed with the independent variable of condition (baseline, fatigue, rest) and dependent variable RCOF. An alpha value of 0.05 was used.

## RESULTS AND DISCUSSION

Condition was significant for peak RCOF ( $p=0.0006$ ). Following rest or fatigue, subjects were able to significantly decrease their peak RCOF compared to baseline walking (Figure 1). Additionally, peak RCOF values after rest were significantly lower than after fatigue.



**Figure 1:** Mean peak RCOF for each condition. Standard deviation bars are provided. \* Denotes significance between all conditions.

It is difficult to distinguish between anticipation and fatigue. Previous research has shown that following a slip subjects alter their gait when anticipating a slippery surface. Specifically, subjects lower their peak RCOF. This is thought to lower the risk of experiencing another slip. [3-5]. Similarly, it was found here that subjects lowered their peak RCOF following the first slip regardless of fatigue group. This reduction puts them at a lower risk of slipping. [3].

Interestingly, there was a significant difference between rest and fatigue. Following fatigue, although subjects lowered their peak RCOF compared to BD, they were not able to lower it as much as following rest. These findings suggest that even with the potential presence of slip anticipation, fatigue effects may prevent firefighters from maximally reducing their risk of slipping. An increased risk of slipping following fatigue has been noted previously. Parijat et al. found that RCOF increased following fatigue. This increase in RCOF translates to an increase in slip risk [4,5].

It is important to note that our fatigue protocol consisted of full-body fatigue similar to an occupational setting whereas, Parijat et al. only fatigued the quadriceps group [4,5]. Additionally, a potential limitation of our experimental design is the challenge of teasing out fatigue and anticipation effects. It is also possible that we are limited by a small sample size and unknown effects of fire-protective equipment during gait and slipping [2]. With the results presented, RCOF values indicate that following fatigue, subjects were at a higher risk of slipping.

## CONCLUSION

It was found that subjects lowered their peak RCOF following the first slip. This reduction puts them at a lower risk of slipping. Following fatigue, subjects were not able to lower peak RCOF as much as following rest. These findings suggest that even with the potential presence of slip anticipation, fatigue effects may prevent firefighters from maximally reducing their risk of slipping.

## REFERENCES

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