

# Deciphering Workers' Safety Attitudes by Sensing Gait Patterns

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**Abstract.** Workers' unsafe behaviors are a top cause of safety accidents in construction. In practice, the industry relies on training and education at the group level to correct or prevent unsafe behaviors of workers. However, evidence shows that some individuals were identified to be showing risky behavior repeatedly and have a high rate to be involved in accidents and current safety training approach at the group level may not be effective for those workers. A worker's evaluation of a hazard (risk perception) and tendency to take/avoid risks (risk propensity) determines how they respond to a hazard and identifying those workers with biased risk perceptions and high risk propensity can thus provide an opportunity to prevent behavior-based injuries and fatalities in the workplace. However, as risk perception and propensity are influenced not only by inherited personal traits (e.g. locus of control) but also by specific situational factors (e.g. mood and stress level), existing approaches relying on surveys are not sufficient when measuring workers' risk perception and propensity continuously in day-to-day operations. In this context, this study examines the potential of ambulatory and continuous gait monitoring in the workplace as a means of identifying workers' risk perception and propensity. Two experiments simulating construction work environments were conducted and subjects' gait patterns in hazard zones were assessed with inertial measurement unit (IMU) data. The experimental results demonstrate changes in gait patterns at pre-hazard zones for most of the subjects. However, the results fail to identify the relationship between gait pattern changes at pre-hazard zones and risk propensities assessed using the Accident Locus of Control Scale.

**Keywords:** Behavioral adaptation · Human risk propensity · Gait Abnormality · Safety management

## 1 Introduction

Unsafe behavior on the part of construction workers is one of the main reasons for accidents in the construction industry [1]. Current practices to prevent and correct workers' unsafe behavior rely mostly on training and education conducted at the group level. However, substantial evidence indicates some people tend to be involved in workplace accidents more often than others [2] and training or education at the group

level may not be effective in preventing individual risky behavior [3–5]. Such differences in accident rates are mainly due to individual differences in perception and/or attitudes towards safety risks [6]. Self-reported interviews [7–9] and biological components [10] confirmed the existence of these individual differences in perception and/or attitudes towards safety risks [11, 12]. Measuring and understanding individual workers' risk perception and propensity (risk taking tendency) [13] is thus critical in identifying risk-prone workers and providing appropriate individualized interventions to prevent their risky behavior.

Many studies that have attempted to measure workers' risk perception and propensity mostly rely on questionnaires and surveys [14–16]. However, social desirability bias leads to inaccuracy in reports, which means people tend to over-report good behavior and under-report bad behavior [17]. Moreover, risk perception and propensity are often affected by situational-specific factors (e.g. temporary mood and goal imminence) [18, 19], and existing approaches cannot continuously capture such changes in workers' attitudes toward risks in day-to-day operations.

In a high-risk workplace where a worker repeatedly encounters multiple safety hazards, such as a construction site, a worker's risk perception and propensity determines how they detect and prepare for potential hazard risks (risk preparedness). Observing and measuring workers' behavioral changes upon encountering hazards (behavioral adaptation) may provide an opportunity to decipher workers' risk perceptions and propensities. This study examines the potential in assessing workers' gait patterns as measurable behavioral markers of individual workers' responses to hazards. Specifically, this study investigates whether workers' gait patterns manifest their behavior adaptations when interacting with hazards and how observed changes in gait patterns can be related to individual differences in risk perception and/or propensity. Two experiments that exposed subjects to various pre-defined hazard zones were designed and conducted to answer these research questions.

## 2 Assessment of the Gait Adaptation upon Hazards

### 2.1 Purpose and Experimental Setup

Experiment 1 examined whether workers' gait patterns measured by a wearable inertial measurement unit (IMU) reflected behavior adaptations developed through interacting with hazards. This laboratory experiment was designed to simulate the working environment of ironworkers, providing a simple testbed to easily estimate subjects' locations and control subjects' movement trajectories toward hazards. Eight healthy naïve subjects were recruited and asked to wear safety boots, safety harnesses and a safety helmet, with an IMU sensor on the right ankle. Two types of hazards were tested in the experiment: obstacles that may cause trip accidents and slippery surfaces that may cause slip accidents. The subjects were asked to walk at a comfortable speed on an elevated I-beam (4 inches in width and 80 ft in length) in four different conditions: (1) and (2) an obstacle located at 30 ft and 50 ft from the starting point of the I-beam; and (3) and (4) a slippery surface located at 30 ft and 50 ft from the starting point of the I-beam. The subjects then underwent ten trials with each condition. Figure 1 shows the

experiment setting and subject participant. Details of the experiment can be found in [20].



**Fig. 1.** Laboratory experiment environment. (a) Slippery surface, (b) obstacle, (c) subject participating in the experiment.

## 2.2 Gait Pattern Assessment

IMU data was used to assess workers' gait patterns. In order to observe how a worker generated different gait patterns in order to adapt to the risk of hazards, we assessed the abnormalities between observed gait cycles as compared to workers' normal gait patterns. We thus used the IMU-based Gait Abnormality Score (I-GAS) developed by Yang et al. [21] with computed gait features (e.g., stride time, stride length). In this approach, the authors estimated the abnormality of gait and the gait features were computed into one score to measure the deviation of a subject's momentary gait stride from their normal gait strides. The I-GAS was calculated as follows:

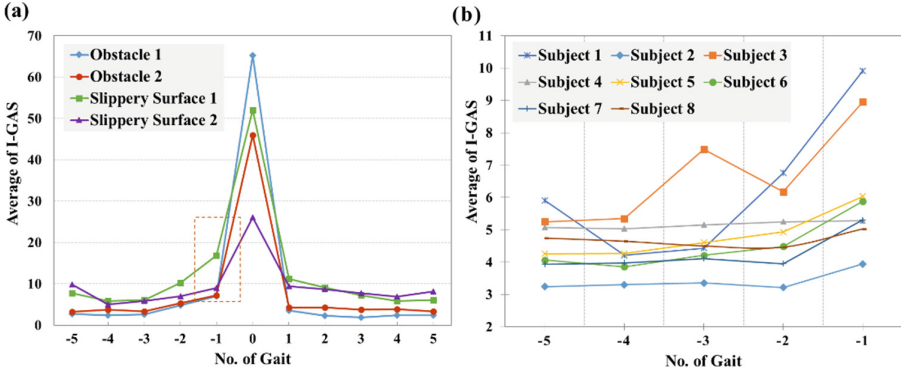
$$I - GAS = \sqrt{(x - \bar{y})C^{-1}(x - \bar{y})^T} \quad (1)$$

In this equation,  $x$  represents the vector of the observed samples and the computed gait features,  $\bar{y}$  represents the vector of the mean value of referenced samples and the computed gait features, and  $C^{-1}$  is the inverse covariance matrix of reference data.

## 2.3 Results

We selected the gait where the subject encounters the hazard as the reference point (Gait 0) and calculated I-GAS values of ten steps from Gait -5 (five steps before Gait 0) to Gait +5 (five steps after Gait 0). Figure 2a illustrates the I-GAS values of one subject. Each line within Fig. 2a represents the average I-GAS values of one subject through ten trials in four different hazard conditions. The I-GAS score peaks at Gait 0, when encountered hazards (e.g., stepping on obstacles) significantly affected gait patterns. However, Gait -1 also showed relatively high values compared to other gaits. This pattern was observed across all four hazard conditions, which indicates that such changes may not be a random alteration due to human movement variability [22] and may instead result from behavioral adaptations mitigating the risk of the hazards.

Figure 2b presents average I-GAS values for eight subjects from Gait -5 to Gait -1. The similar pattern of high I-GAS values in Gait -1 was also observed in most



**Fig. 2.** Results of Experiment 1: (a) a subject’s I-GAS values in different experimental conditions, (b) average I-GAS values of different subjects.

subjects. The t-test results confirmed the difference between I-GAS values at Gait -1 compared to previous gaits in most of the subjects (Table 1). This indicates the potential of using I-GAS values upon encountering hazards (e.g., Gait -1) as measurable behavioral markers of individual workers’ responses to hazards. Individual differences in such patterns are also observed. For example, some subjects (Subject 1 and 3) were observed to present high I-GAS values at earlier gaits (Gait -2), while Subject 4 does not present much change in I-GAS values from Gait -5 to Gait -1.

**Table 1.** T-test results of eight subjects

	Gait -3 and Gait -1		Gait -2 and Gait -1	
	Mean difference	t	Mean difference	t
Subject 1	5.48	-5.41***	3.16	-2.68**
Subject 2	1.20	-2.95**	1.36	-3.54***
Subject 3	1.69	-2.48**	1.34	-2.06*
Subject 4	1.43	-2.11*	1.11	-1.58
Subject 5	0.62	-1.22	0.71	-1.68*
Subject 6	-0.10	0.11	-0.51	0.57
Subject 7	1.47	-0.48	2.78	-1.12
Subject 8	1.00	-1.14	1.08	-1.24

\*  $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

### 3 Gait Adaptation and Risk Propensity

#### 3.1 Purpose and Risk Propensity Measurement

Experiment 2 was designed and conducted to further investigate whether individual differences in gait adaptations are related to subjects’ attitudes toward risks (risk

propensity). To measure subjects' risk propensities the Accident Locus of Control Scale (ALCS) was used in this experiment.

Psychologists often use scales based on surveyed personal traits to measure human risk propensity because such personal traits are considered a strong influencer of risk behavior [23]. However, risk propensity differs markedly across contexts, meaning it is possible that an individual is risk seeking in some areas, like health, but risk averse in others, like finance [23]. Locus of control is a personal cognition concept reflecting an individual's belief about who or what controls their life events [24]. Individuals with an internal locus of control perceive that they can exert control over the outcome of a situation, while individuals with an external locus of control attribute outcomes to external factors, such as luck, the environment or others' behavior. In the domain of safety, people with internal locus of control are likely to be more safety conscious than those with external locus of control [25], and individuals with specific training or more experience tended to be more internal orientation [26]. The internal-external locus of control theory, developed by Rotter [24], has been used successfully as a means of predicting involvement in accidents [27–29]. The ALCS is a 24-item questionnaire developed by modifying the general locus of control scale to fit job hazards and risk at work [26]. Each item includes two statements representing situations of internal and external locus of control, subjects were asked to select the one they believe is more true. Subjects who choose the external viewpoint score 1, with a higher score indicating a more external locus of control and a higher likelihood of taking risks. Janicak has used this scale to successfully predict workers' involvement in accidents [26].

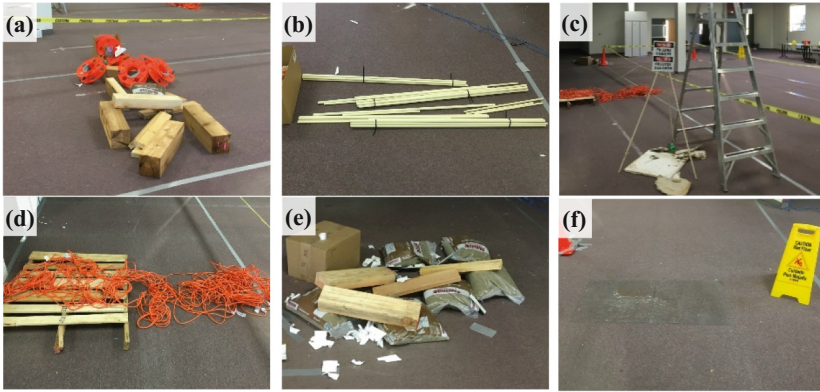
Subjects' ALCS scores were compared to their gait adaptations observed in the below experiment.

### 3.2 Experimental Setup

This experiment was designed to simulate bricklaying work at a construction site in an open indoor space. Subjects were required to walk and lay bricks at selected working areas. Six types of hazards were installed along the anticipated paths taken by the subjects (Fig. 3). A survey area was established next to the operation area in order to minimize time variation when measuring risk propensity in the experiment. Subjects were asked to complete a survey using a tablet computer and then start the experiment immediately. 32 subjects participated in this experiment, with 25 having previous experience in construction. During the experiment the subjects were required to wear (1) an IMU sensor on the right ankle, (2) a safety helmet with a localization sensor and (3) safety shoes and vests. Their gait features were recorded by IMUs and the entire experiment was video-recorded to provide reference data for further analysis.

### 3.3 Results

Subjects with high ALCS scores are assumed to have a tendency to take/ignore risks compared to subjects with low ALCS scores, who have a tendency to avoid risks. It was thus hypothesized that subjects with high ALCS scores have smaller gait



**Fig. 3.** Hazards installed for the experiment: (a) unavoidable obstacle, (b) unstacked pipes, (c) warning sign for falling object, (d) unorganized wire, (e) avoidable obstacle, (f) slippery surface.

adaptations (less risk preparedness) compared to subjects with low ALCS scores. Data analysis of Experiment 2 was guided by this hypothesis.

ALCS includes 24 items, yielding a score ranging from 0 to 24 in total; a score of zero indicates a subject has a completely internal locus of control, while a score of 24 indicates that a subject has a completely external locus of control. Table 2 lists the ALCS scores of all 32 subjects.

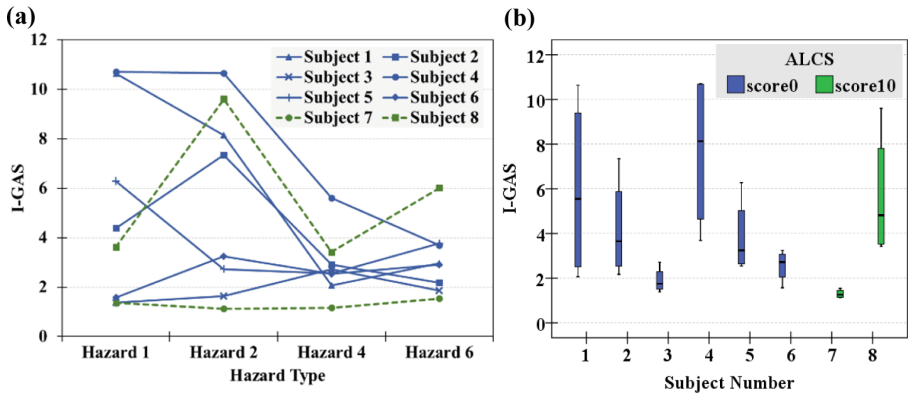
**Table 2.** Accident locus of control scale scores for 32 subjects

	Accident locus of control scale score									
	0	1	2	3	4	5	7	9	10	
No. of subjects	6	2	4	3	7	3	3	2	2	

We can see from these results that all subjects involved in the experiment tended to have lower ALCS scores. Two subjects have the highest score of 10 and six subjects have the lowest, 0. We thus compared gait adaptation values between these two groups. Based on the result from Experiment 1, I-GAS values of Gait -1 (one gait before hazard zone) were computed to represent gait adaptation values for the two groups.

A subject’s first three encounters with each type of hazards (out of a total of eighteen encounters) were included to assess gait adaptations, as gait adaptations in subjects tend to decrease with each following encounter. In addition, two avoidable hazard types, including the falling object warning sign (Fig. 3c) and the avoidable object (Fig. 3e), were excluded in computing gait adaptations. Most of the subjects avoided these hazards by changing their paths and did not present any significant gait adaptations when encountering these hazards.

Figure 4a illustrates average I-GAS values for each type of hazard, while Fig. 4b represents I-GAS distributions for each subject. Subjects with score 0 are shown in blue



**Fig. 4.** Results of Experiment 2: (a) average I-GAS values for different hazards, (b) I-GAS distributions of individual subjects with ALCS scores 0 and 10. (Color figure online)

(blue solid lines in Fig. 4a and blue boxplots in Fig. 4b) and subjects with a score of 10 are shown in green (green dashed lines in Fig. 4a and green boxplots in Fig. 4b).

These results shown in Fig. 4 do not demonstrate any clear difference between the two groups. In particular, two subjects with score 10 show completely different patterns of gait adaptations. For example, Subject 7 tends to have smaller gait adaptations and their variance is small, while Subject 8 has larger gait adaptations with significantly different magnitudes across the hazards. Consequently, these results are not sufficient to confirm any relationship between ALCS scores and gait adaptations.

Although the experiment results fail to provide any meaningful evidence on how gait adaptations to hazards are related to subjects' attitudes toward risks, there are several points that should be considered. First, Subject 8, part of the group with an ALCS score of 10, is the only female subject included in the two comparison groups, and female subjects (3 out of 32 subjects) tend to have higher gait adaptations compared to male subjects. Thus gender needs to be considered and controlled as an independent variable in future experiment designs. In addition, the subjects recruited were university students. While most of them have field experience, the entire subject group has relatively lower ALCS scores. Thus there is a high chance that the difference of risk propensities between the two selected groups may not present differing observable behaviors within the experiments.

## 4 Conclusions

This study investigates whether workers' gait patterns can represent their behavioral adaptations developed to mitigate the risks of hazards. Laboratory experiments were designed and conducted to assess changes in subjects' gait patterns upon encountering simulated workplace hazards. The results indicate that subjects tend to modify their gait patterns even before encountering hazards and individual differences exist in such changes in gait patterns. However, the experimental results fail to confirm any relationship between gait adaptations and risk propensities assessed by ALCS.



Future research needs to further investigate the relationship between gait adaptations and the risk preparedness of workers. As mentioned previously, various personal traits, including gender, should be considered in testing such relationships. In addition, considering the fact that any single existing tool, including ALCS, cannot reliably assess subjects' perceptions and attitudes toward the risks presented within the experiment settings, various existing tools to assess risk perception and attitudes need to be used to further examine any relationship between gait adaptations and risk preparedness.

Insufficient preparedness for hazard of risk-prone workers on the construction site may cause accidents. Identifying risk-prone workers and observing behavioral adaptation for risk preparedness is an effective way to understand their risk perception and risk propensity which allows individual intervention to correct their risk taking behavior. Meanwhile, measuring gait adaptation by collecting bodily response can continuously detect insufficient risk preparedness during construction workers' day-to-day working operation in order to prevent injuries on site and enhance construction safety performance.

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