Effect of calf muscle fatigue on person identification using video sequences of body sway

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***Abstract*—Body sway, which is a slight movement that naturally occurs when a person stands, has attracted attention as an informative cue with which to identify people. In the field of kinematics, analytical studies have revealed that the movement of body sway varies when calf muscles are fatigued. However, the studies have not revealed whether the accuracy of identifying people is reduced by calf muscle fatigue. We investigate the identification accuracy for body sway signals taken from video sequences when fatiguing the target's calves. We find that the power spectral density of each frequency band of body sway is increased by fatigue and that the identification accuracy is significantly decreased. We also find that the magnitude of the velocity of body sway is greater in post-fatigue movement than in pre-fatigue movement.**

***Index Terms*—Body sway, Muscle fatigue, Calf, Identification, Video sequences**

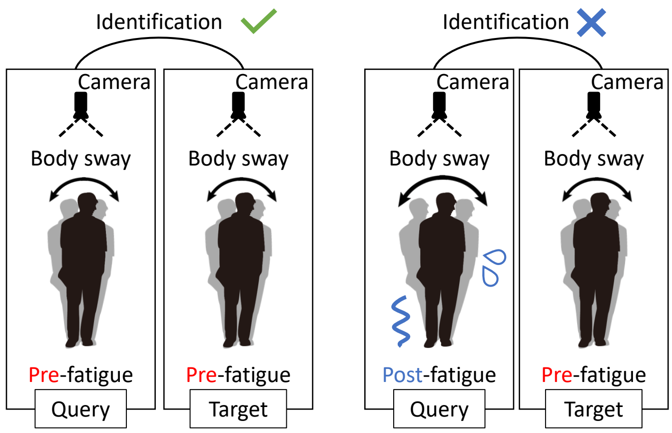


Fig. 1. Effect of calf muscle fatigue on the accuracy of person identification using body movements. The identification accuracy changes significantly depending on the presence or absence of muscle fatigue.

I. Introduction

There is a demand for person identification technology using surveillance cameras with the aim to achieve a safe and secure society [1]–[3]. The accurate identification of people requires informative characteristics representing individuals to be obtained from video sequences acquired with surveillance cameras. As one such characteristic, the body sway of a standing person has recently attracted interest from researchers. Body sway is a slight movement that occurs naturally even when the human body is stationary, as described in [4]. Kamitani et al. [5] demonstrated that the time-series signals of body sway are a characteristic that can be used effectively for person identification. However, they evaluated the identification accuracy under the condition that there was no muscle fatigue.

The human body enters a state of muscular fatigue after strenuous exercise. This muscle fatigue causes changes in body sway, as described in analytical studies of body kinematics [6], [7]. Thus, muscle fatigue might reduce the accuracy of person identification using body sway signals, as shown in Fig. 1. As an example, we might consider the case that a person is incorrectly identified as a different person after engaging in strenuous exercise at a fitness club or gym. However, the relationship between the accuracy of person identification and the muscle fatigue of body sway has not been investigated.

In this paper, we evaluate the effect of muscle fatigue on the accuracy of person identification using time-series signals of body sway. In terms of muscle fatigue, we consider the case that a person's calves are strongly loaded. In the following, we refer to the state before calf loading as the pre-fatigue state and the state after calf loading as the post-fatigue state. Our evaluation results reveal that the identification accuracy is significantly worse for post-fatigue query samples than for pre-fatigue query samples. The power spectral densities computed from the time-series signals of body sway show significant differences among the components in various frequency bands. We also find that the magnitude of the velocity of movement for body sway in various directions is greater post-fatigue than pre-fatigue.

II. Related work

In the field of body kinematics [6]–[9], the relationship between muscle fatigue and body sway has been analyzed when a specific body part is loaded. When a load is applied to the neck [9], there is no significant difference in the location of the center of pressure (CoP) of body sway. Additionally, there is no significant difference in the velocity of the CoP appears when a load is applied to the upper arm [6]. In contrast, the velocity of the CoP increases significantly when a load is applied to the groin [8] or the calf [6], [7]. Body sway thus varies depending on which body part is fatigued. In particular, the slight movement of body sway is greatly affected by a load applied to the lower part of a person's body. In this paper, we investigate the effect of the fatigue of a body part of the lower body on the accuracy of identification using body sway. We used an overhead camera to observe body sway signals though the analytical studies [6]–[9] used a footplate pressure sensor.

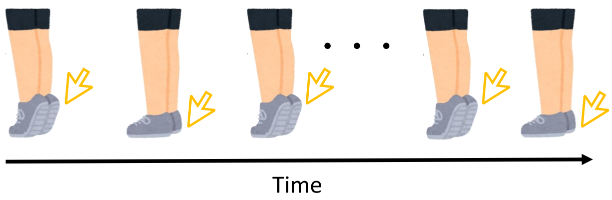


Fig. 2. Heel lift exercise in our experiments

III. Evaluation Method

A. Fatiguing a body part

We focus on the calf as the body part that is fatigued. The gastrocnemius and soleus muscles are located under the skin of the calf. As described in [10], the gastrocnemius and soleus muscles are known as the triceps surae and are responsible for flexing the ankle joint and maintaining a person's standing posture.

We evaluate the following hypothesis, assuming that the pre-fatigue features are stored as target samples.

- When post-fatigue features are input as query samples, the identification accuracy is lower than that in the case that pre-fatigue features are input as query samples.

B. Procedure of fatiguing the calves

We describe the procedure of fatiguing the calves. Initially, we had the participants stand on a floor without shoes. As shown in Fig. 2, we had the participants perform a heel lift exercise in which they alternately raised and lowered their heels with a constant rhythm. The participants repeated this exercise until they reached the post-fatigue state. The exercise was terminated if a participant failed to match the constant rhythm in three attempts or voluntarily called a halt to the exercise. We instructed the participants to not bend their knees as much as possible and raise their heels as high as possible so as not to apply a large load to body parts other than the calves.

C. Feature extraction for person identification

Person identification is a technique for determining whether a person in a query video sequence is contained in the target dictionary. To obtain high identification accuracy, it is important to extract features from the video sequences of body sway. In this paper, we extract spatio-temporal features by calculating the amount of movement of body sway at each time from the video sequence using an existing method [5]. Figure 3 shows the procedure of feature extraction, the details of which are described below.

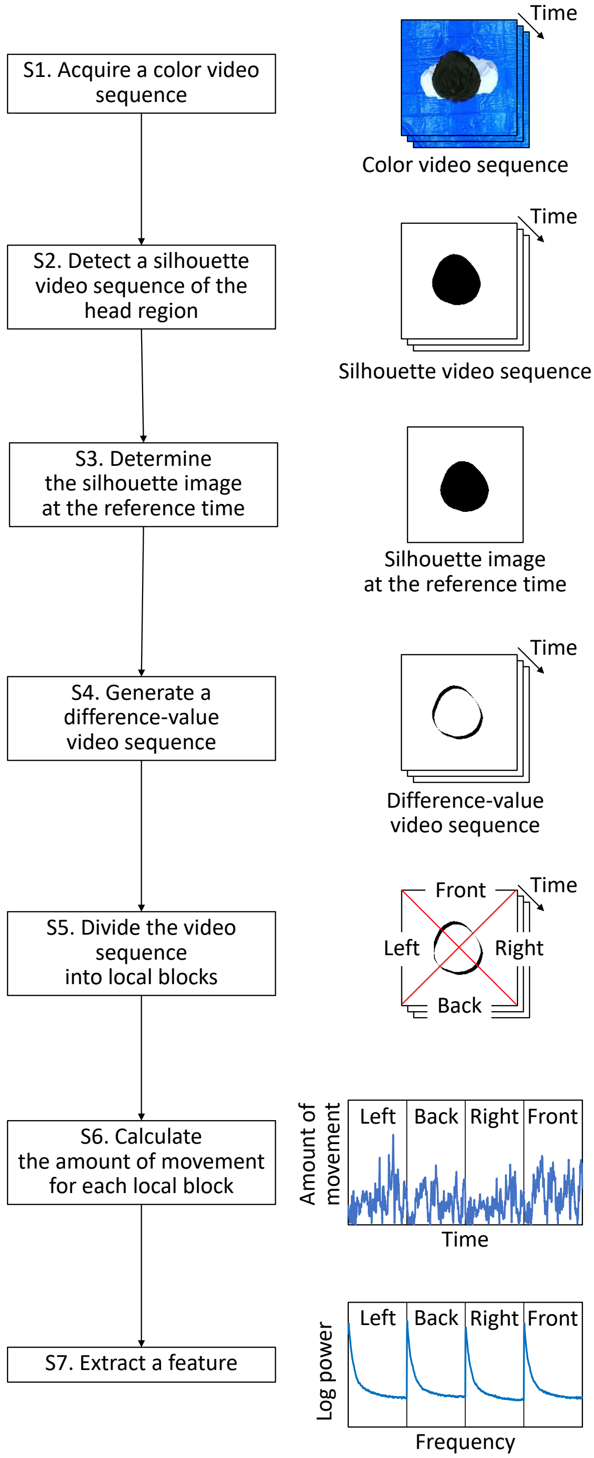
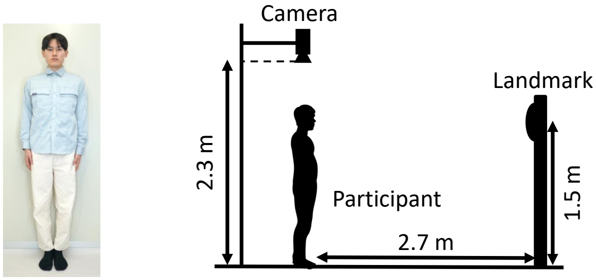


Fig. 3. Overview of feature extraction for person identification using the video sequences of body sway

In S1, we obtain a color video sequence of body sway using a commercially available camera. To observe the head region, which is the body part that moves the most in body sway, we place a camera above the head. We assume that a person stands in an upright posture under the overhead camera. In S2, we detect a silhouette video sequence of the head region from the color video sequence. A pixel value is set at 1 for the head region and 0 otherwise. In S3, the reference time of each silhouette video sequence is determined. In the silhouette video sequence, we find a representative silhouette image similar to the remaining silhouette images at various times. The time of this representative silhouette image is used as the reference



(a) Upright posture (b) Environment

Fig. 4. Experimental setting

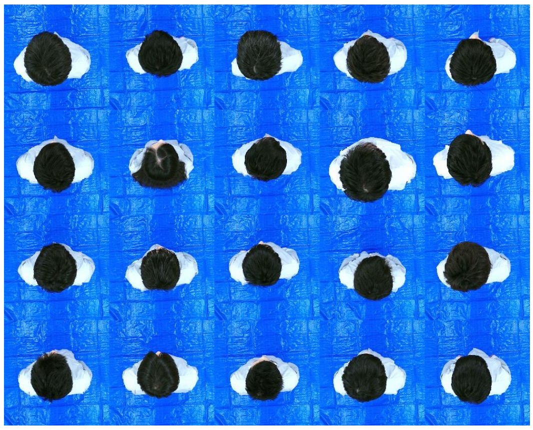


Fig. 5. Part of a color video sequence acquired with the overhead camera

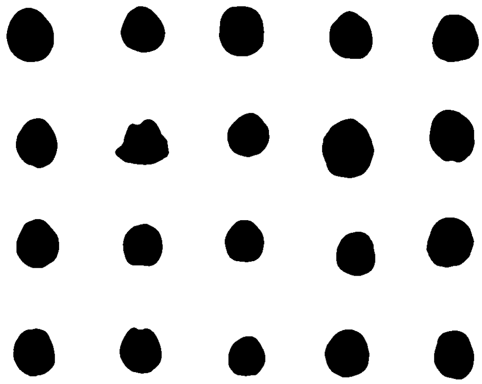


Fig. 6. Part of a silhouette video sequence of the head region

time. In S4, we generate a difference value image to extract the movement of the head region at each time. We compute the difference in pixel values between the silhouette image at each time and the representative silhouette image at the reference time. In S5, we divide the difference value image into local blocks to observe the spatial difference in head shape. Specifically, we divide the head region into I blocks radially from the center of the head region. In S5 of Fig. 3, the number of local blocks $I = 4$ is used as an example. In S6, we calculate the amount of movement at each time to extract the temporal change in the head region. In each local block, the sum of the difference values is obtained and used to represent the amount of movement at each time. In S7, we extract features for person identification. In each block, the power spectral density (PSD) is calculated from the time-series signal of the amount of movement. The PSDs of all blocks are concatenated to determine the feature vector for identification.

IV. Experiments

A. Dataset

We acquired pre-fatigue and post-fatigue video sequences to evaluate the effect of calf fatigue on identification accuracy. Twenty participants (age: 22.6 $\pm$ 1.5 years, height: 168.3 $\pm$ 5.6 cm, weight: 60.4 $\pm$ 10.9 kg) participated in the experiment. The participants wore the same work clothes and did not wear shoes. We instructed the participants to maintain the upright posture shown in Fig. 4(a), stand under the camera, and gaze at a landmark. The alignment of our experimental setting is shown in Fig. 4(b). We show part of a color video sequence in Fig. 5 and part of a silhouette video sequence in Fig. 6.

In the following procedure described in Fig. 7, we acquired two pre-fatigue video sequences and one post-fatigue video sequence. We refer to the first pre-fatigue video sequence as V_{B1}, the second pre-fatigue video sequence as V_{B2}, and the post-fatigue video sequence as V_A. The time length of each video sequence was set at 120 s. Each participant took a 60-second break between V_{B1} and V_{B2} and another 60-second break between V_{B2} and the heel lift exercise. We started the acquisition of V_A within 15 seconds of the end of the exercise. We used a camera having a resolution of 1920×1080 pixels and a frame rate of 30 fps. The video sequence was cropped to 300×300 pixels, centering on the head region.

We here give the statistics of calf fatigue for the heel lift exercise described in Section III-B. The constant rhythm of the heel lift was set at 100 times per minute. Different participants were able to raise their heels a different number of times, as shown in Fig 8. More than half of the participants completed the heel lift exercise fewer than 400 times. In contrast, five participants completed the heel lift exercise more than 800 times.

B. Accuracy of person identification

We first describe the setup of our experiments for the identification method described in Section III-C. The features of V_{B1} were used as the pre-fatigue target samples, the features of V_{B2} as the pre-fatigue query samples, and the features of V_A as the post-fatigue query samples. On the basis of the hypothesis described in Section III-A, we calculated the identification accuracy when the pre-fatigue V_{B2} and post-fatigue V_A were input. The identification accuracy depends

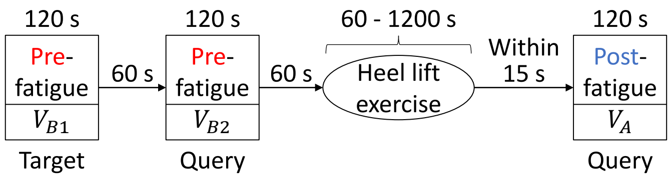


Fig. 7. Procedure of video sequence acquisition

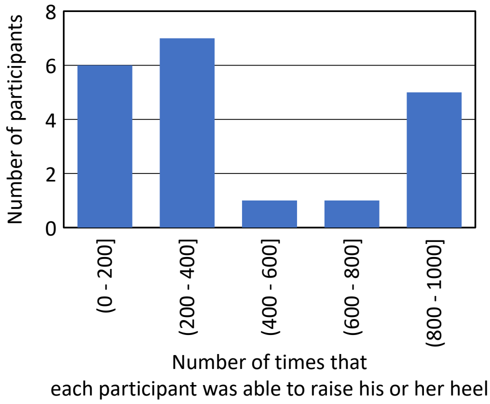


Fig. 8. Histogram of the number of heel lifts performed by each participant in reaching calf muscle fatigue

on the individuals included in the target samples, and we thus generated subsets of 18 individuals randomly selected from the 20 participants. We generated 10 subsets and calculated the mean and standard deviation of the identification accuracy for the subsets. The accuracy metric was the rank-1 correct-match rate. We used the nearest neighbor based on the Euclidean distance for identification.

Table I gives the accuracy when using pre-fatigue query samples and post-fatigue query samples. We found that the accuracy was about 59 points lower for the post-fatigue query than for the pre-fatigue query. A statistical test was performed to determine if the decrease in the identification accuracy was significant. Specifically, we used the Mann–Whitney U test, with a significance level of $p < .01$. As a result, we confirmed that there was a significant difference in the accuracy between pre-fatigue and post-fatigue states.

C. Visualization of changes in features

To investigate the reason for the decrease in identification accuracy, we compared the pre-fatigue feature V_{B2} and the post-fatigue feature V_A. We used the feature extraction method described in Section IV-B. The difference between the post-fatigue feature and pre-fatigue feature was calculated for each participant at each frequency. The number of blocks was set to four, as shown in S5 of Fig. 3. We computed the absolute value differences between the features for each of the four blocks. Figure 9(a) shows the average of the pre-fatigue feature, (b) shows the average of the post-fatigue feature, and (c) shows the absolute value difference between the pre-fatigue and post-fatigue features. In the front block, we find that there were large differences in the components of various frequencies.

TABLE I
IDENTIFICATION ACCURACIES FOR PRE-FATIGUE AND POST-FATIGUE QUERY SAMPLES. SIGNIFICANCE AT THE LEVEL OF $p < .01$ IS DENOTED BY **.

Pre-fatigue query	Post-fatigue query	Statistical test
92.2 ± 2.9 %	33.3 ± 3.7 %	**

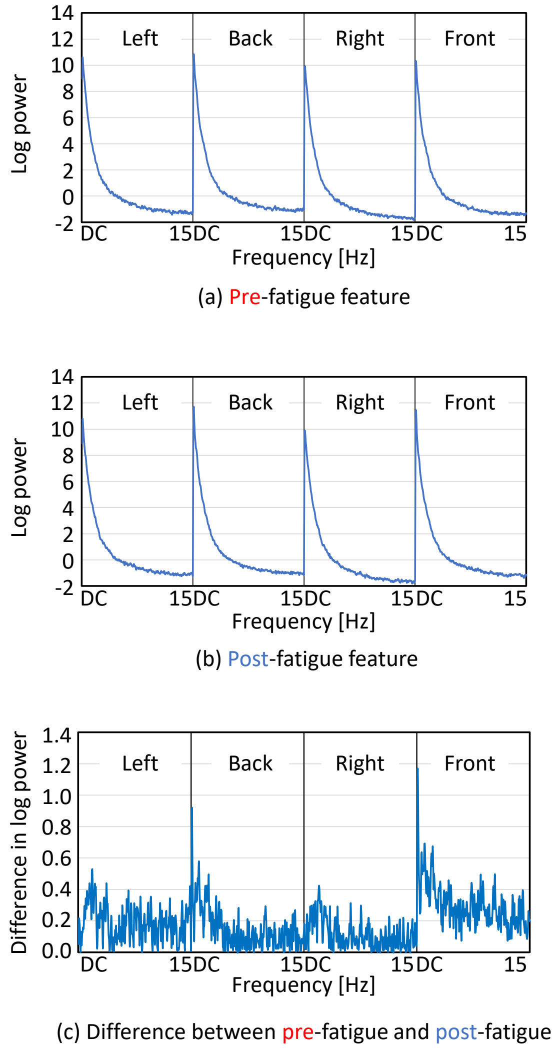


Fig. 9. Comparison of average pre-fatigue and post-fatigue features

The same tendency is observed in the left, right, and back blocks. We thus believe that calf fatigue had an effect on body sway and accounts for the decrease in identification accuracy.

V. EFFECT OF CALF FATIGUE ON BODY SWAY

A. Purpose

We further investigated what changes in body sway are caused by calf fatigue. A previous study [6] analyzed the effect of calf fatigue on body sway in mediolateral (ML) and anterior–posterior (AP) directions. Observations in the ML direction correspond to viewing the participant from the

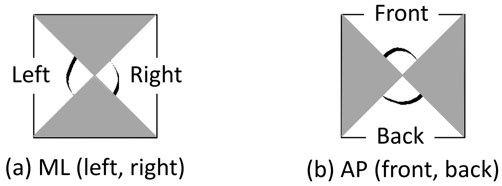


Fig. 10. Local blocks for MP and AP directions

side whereas observations in the AP direction correspond to viewing the participant from the front. The analytical study [6] found that calf fatigue significantly increases the magnitude of the velocity of movement in the ML and AP directions. However, the study used a foot pressure sensor to observe the movement of body sway. In contrast, we used a camera to observe the body sway.

B. Calculation of the magnitude of the velocity of movement

We describe a method for extracting the magnitude of velocity of movement in body sway from imagery taken with a camera. Feature extraction is first performed following S1 to S6 in Fig. 3, and the amount of movement is then extracted. We compute the magnitude of the velocity of movement by taking the absolute value after differentiating the amount of movement at each time. We analyze the magnitude of the velocity of movement in ML and AP directions following the analytical study [6]. In the ML direction, the magnitude of the velocity of movement is determined by adding the left-block magnitude and the right-block magnitude, as illustrated in Fig 10(a). In the AP direction, the magnitude of the velocity of movement is determined by adding the front-block magnitude and the back-block magnitude, as illustrated in Fig 10(b).

C. Experimental results

We compared the magnitude of the velocity of movement between pre-fatigue V_{B2} and post-fatigue V_A, targeting the participants used as a query for the identification in Section IV-B. Figure 11 compares the magnitude of the velocity of movement between pre-fatigue and post-fatigue states in ML and AP directions. We performed the Mann–Whitney U test with a significance level of $p < .01$. We see a significant difference in the magnitude of the velocity of movement between pre-fatigue and post-fatigue states for both ML and AP directions. In agreement with the result of the analytical study [6], the magnitude of the velocity of movement was higher in the post-fatigue state than in the pre-fatigue state. We consider that this difference increased the PSD in each frequency band, as described in Section IV-C.

VI. Conclusions

We evaluated the effect of muscle fatigue on the accuracy of person identification using video sequences of body sway. The evaluation results revealed that the identification accuracy was significantly worse for the post-fatigue state than for the pre-fatigue state. We confirmed that the power spectral densities computed from the time-series signals of body sway

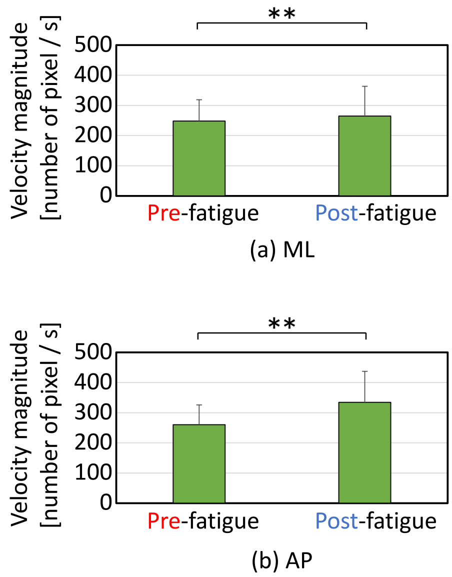


Fig. 11. Comparison of the average velocity magnitude between pre-fatigue and post-fatigue states. Significance at the level of $p < .01$ is denoted **.

show significant differences among the components in various frequency bands. We also confirmed that the magnitude of the velocity of movement in body sway was greater post-fatigue than pre-fatigue when observed in AP and ML directions.

As future work, we intend to develop a robust method against calf fatigue that will increase identification accuracy and extend the evaluation of the effects of muscle fatigue to different body parts.

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