Pseudo Forces from Asymmetric Vibrations Can Modulate Movement Velocity

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Abstract. We demonstrate vibrotactile haptic guidance that uses the illusion of pseudo-forces created by asymmetrical vibrations. This particular vibration pattern is zero-mean, but asymmetrical, such that half of the cycle's peak acceleration is significantly higher than the other half, with the amount of asymmetry being tunable. During our experiment, 19 participants correctly perceived the direction of the pseudo force. Moreover, we observed that the elbow flexion velocity was naturally modulated by the amount of asymmetry in the waveform (Pearson's $r = 0.84$, $\text{p} < 0.01$), despite participants not having been provided specific instructions. These results pave the way for an embedded, unobtrusive and effective method to provide movement guidance using pseudo-forces.

Keywords: Pseudo forces · Asymmetric vibrations · Vibrotactile guidance

1 Introduction

Haptic guidance can help users to execute the right movement at the right pace. This guidance typically uses desktop haptic devices or exoskeletons to apply directional forces as a function of the user's movement. However, these devices are complex and costly, limiting their wide-scale adoption. In contrast, some researchers have turned to vibrotactile feedback using lightweight and inexpensive actuators. But most attempts to guide movement with vibrotactile feedback are cognitively demanding and less intuitive. We postulate that these vibrotactile sensations are not integrated as guiding signals because they are incongruent to the sensation of slow-varying forces present in natural physical interactions.

Amemiya et al. showed that asymmetric vibrotactile signals, where one half-cycle had a significantly larger amplitude than the other half, could generate the illusion of a pseudo-force [2]. Subsequent studies have demonstrated that these pseudo forces can provide directional cues [1, 3]. In light of these results, we ask: could we use asymmetric vibrations to elicit a sensation of pseudo-force to guide the speed and direction of the user's movement?

In this preliminary study, we explore how the amount of asymmetry of the waveform can modulate the velocity at which a participant performs elbow flexion. Affecting the dynamics of movements can enable vibrotactile haptic guidance

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in situations where conventional haptic guidance is difficult to implement, such as in sports training and remote physiotherapy.

2 Methods

Asymmetric waveform generation: The waveform played by the vibrotactile actuators is the second time derivative of the motion equation proposed in Amemiya et al. [2] that models a slider-crank mechanism, see Fig. 1a.

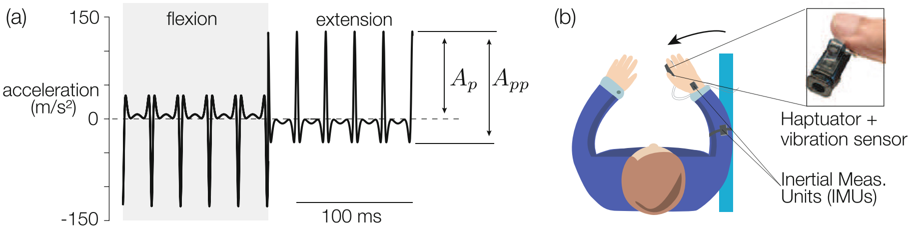

Fig. 1. (a) Example of a waveform with an asymmetry index of 0.61. (b) Experimental setup including the vibrotactile actuator, accelerometer and inertial measurement units.

Asymmetry Index. To quantify the amount of asymmetry of the vibration, we define the asymmetry index, $\Gamma = A_p/A_{pp}$ where, A_p is the max amplitude and (A_{pp}) is the peak to peak amplitude. Since the shape of the waveform is a function of frequency, its asymmetry index also depends on the frequency. This dependency allows us to tune the asymmetry index by changing the frequency.

Experimental protocol. Participants faced a table marked with resting position, Fig. 1-b. A wide bandwidth vibrotactile actuator (Haptuator) was attached to their thumb. The actual vibration was measured by an accelerometer, from which the asymmetry index was computed. Two inertial measurement units (Xsens Dots) placed on the bicep and forearm, measured the elbow flexion velocity.

Conditions. We generated waveforms with frequencies ranging 10 Hz 100 Hz, with an interval 10 Hz. These waveforms had asymmetry indices ranging from 0 to 0.62. For each frequency, vibrations with a duration of 3 s were randomly provided as input to the participants.

Participants. Nineteen (17M, 2F) adults, from 22 and 30-year-old, participated in the experiment. They wore ear protection and were blindfolded to avoid audio or visual cues. For every trial, participants were instructed to "follow the force", without any instructions about the direction or speed.

3 Results

Perception of the direction. During pilot studies, we validated the perceived direction of pseudo forces. A 2-AFC protocol showed that participants correctly perceive directional cues in the elbow flexion or extension direction for asymmetric vibration ($96 \pm 4.66\%$). In contrast, with symmetric vibration, the rate of success was at chance level ($49 \pm 5.61\%$) showing significant differences of performance between both vibrations ($t_{36} = 27.9$, $p < 0.01$), see Fig. 2a. These results are in line with previous reports using pseudo forces for directional guidance [2, 3].

Influence of the Asymmetry index on movement. When evaluating the movement velocity for each condition, we find a positive correlation (Pearson's $r = 0.84, \text{p} < 0.01$) between the asymmetry index of the vibration and the angular velocity of the elbow, see Fig. 2b. This correlation indicates that larger asymmetry indices correspond to larger elbow flexion velocities.

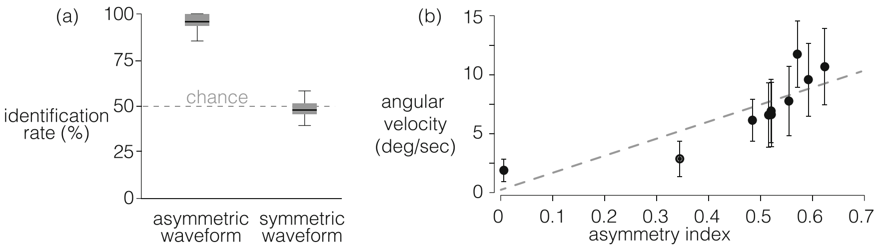

Fig. 2. (a) Influence of symmetry on the identification of direction. (b) The angular velocity of elbow flexion is correlated to the asymmetry index.

4 Discussion and Conclusion

We demonstrate an intuitive method to modulate users' elbow flexion velocity by varying the amount of asymmetry. This can be due to greater skin deformation caused by the attached haptuator when vibrated with a waveform having higher asymmetry index. These findings point toward ways to modulate the intensity and direction of pseudo forces by varying the shape of the waveform, thus providing an effective way to guide movements of users. Nonetheless, the velocities are variable between participants and their precise control would require clear instructions.

In future research, we will investigate how to tune the asymmetry index independently of the frequency and study the effect of varying the pseudo-forces as a function of the user's movement. Our findings show that pseudo-forces can be used to provide remote movement guidance with inexpensive and wearable devices, thus allowing haptic feedback in daily activities.

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