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Influences of Tactile Sensation on Pinch Force under Loaded and Unloaded Conditions

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Abstract: Although researchers have studied various parameters that affect grip force, few studies investigate the effects of tactile sensation on pinch force. This study aims to determine the influences of tactile sensation on pinch force with a special emphasis on screw knobs under loaded and unloaded conditions. The participants included 32 manual workers who were required to pinch and turn the knobs to generate pinch force under reduced and increased sensations simulated using cotton and nitrile gloves. The data were analysed using the analysis of variance via Minitab 16. Results show that the pinch force exerted for reduced sensations is higher than that of increased sensations because the reduced friction increased skin-object slippages, which caused participants to spontaneously increase their force to prevent slippages. This study serves as a guideline to potentially improve the design of objects operated with pinch grips to be safe and suitable for manual, sedentary or general tasks.

Keywords: Tactile Sensation, Pinch Force, Musculoskeletal Disorders, Hand-Related Musculoskeletal Disorders, Hand Injuries, Load Condition

Introduction

High-force pinch tasks are common risk factors associated with the development of hand cumulative trauma disorders in many occupational activities (Eksioglu *et al*., 1996; Shivers *et al*., 2002). Some cumulative trauma disorders also present symptoms which include a diminished sense of touch which disallows workers from performing tasks such as pinching (Sesek *et al*., 2007). This sensory disability hinders individuals from manipulating hand-related tasks since they often crush fragile objects easily or drop them (Nowak *et al*., 2003).

Based on studies done by the National Institute for Occupational Safety and Health (NIOSH), it was suggested that there is an average of 25 hand injuries occurring each year for every 10,000 workers (Ng *et al*., 2014). Al-Husuny (2011) reported that 24.7% of industrial accidents recorded at Serdang Hospital are work-related hand injuries, with over 46.2% of these cases considered severe.

The aforementioned justifications beg the need for researchers to study the effects of certain parameters on grip force and pinch force in order to better understand the behaviour of forces exerted by the hand with varying conditions. Extensive studies have been carried out on grip force and the parameters that affect grip force, such as torque direction, object size and technique (Enders and Seo, 2011; Seo and Armstrong, 2008; Seo *et al*., 2008a; 2008b). However, there appear to be no studies that investigate the effects of tactile sensation on pinch force. This research explores the effects of tactile sensation on pinch force with an emphasis on loaded and unloaded conditions.

Tactile Sensation

Tactile sensation or sensation can be defined as a physical feeling or perception resulting from something that happens to or comes into contact with the body (Delong *et al*., 2007). One of the most essential roles of the hand is the capability to perceive sensation. As an active sensory organ, the hand can detect objects even when there is no visual input and can perceive different object shapes, object sizes and surfaces (Trew and Everett, 2005).

Sensory-disabled individuals however, are diminished of their sense of touch due to sensory deficits of the median nerve and they often face problems pertaining to manual motor activities (Nowak *et al*., 2003). Their disability to use the hand in manipulative tasks causes them to frequently drop objects, easily crush fragile objects and normally face problems in buttoning their shirt while dressing (Nowak *et al*., 2003). It appears that individuals with sensory impairment disorders such as carpal tunnel syndrome exert larger grip forces when hitting their hand-held tool against an object (Lowe and Freivalds, 1999; Nowak *et al*., 2003).

The sensation of a more secure grip with less skin-object slippage when gripping a high-friction surface object allows individuals to apply lower grip forces compared to when gripping a low-friction object surface (Enders and Seo, 2011). However, reduced sensation may cause an individual to exert a higher level of grip force (Huysmans *et al*., 2008). During a grip, the somatosensory cortex receives sensory information not only for normal force, but also for shear force and skin-object slip (Enders and Seo, 2011; Salimi *et al*., 1999). Thus, individuals who experience a skin-object micro-slippage tend to increase their grip force for low-friction surfaces (Enders and Seo, 2011).

Besides that, researchers have also posited that the use of gloves may alter frictional conditions between the hand and a tool handle; thus, causing the ratio of total grip force to maximum torque output to be different than how it would be in a bare-handed condition (Shih and Wang, 1997). For this study, two types of sensations will be explored, i.e., reduced and increased sensations.

Materials and Methods

In order to accurately measure the pinch force exerted on the screw knobs under a combination of factors, 3 flexiforce sensors (from Tekscan® Inc) were used for this experiment. The sensors can be used to measure both static and dynamic forces (up to 1000 lb or 4446.22 N) and are thin enough to enable non-intrusive measurements. In order to simulate the feeling of increased and reduced sensation, cotton gloves (reduced sensation) and nitrile gloves (increased sensation) were used.

Screw knobs were used as the apparatus for this study since they involve pinch-related activities and can be used generally on almost any machine, hand tool, device or furniture (Monroe, 2013). Based on benchmarking results, 3 commonly manufactured shapes of screw knobs were chosen for this study, which included the cylindrical, spherical and 5-lobes shapes. The benchmarking results also suggested three sizes for all the screw knobs, which included the large sizes, the medium sizes and the small sizes. Figure 1 shows an example of the apparatus for the large knobs.

In order to simulate the loaded and unloaded condition, 2 different structures were used. The loaded condition borrowed the mechanism of a door knob in order to simulate the loading effect when the screw knobs fitted in the mechanism are turned. The unloaded condition involved internal threads where the screw knobs can just be normally screwed in using their external threads.

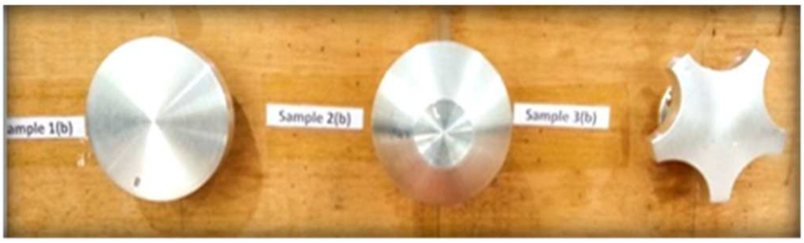

Fig. 1. Large cylindrical, spherical and 5-lobes knobs

Fig. 2. Complete setup of the sensors

A total of 32 manual workers participated in this study. The participants were required to assume a seated posture and have 3 flexiforce sensors attached to their thumb, fore finger and middle finger. The nitrile and cotton gloves were cut into small pieces and pasted with double-sided tape. These small pieces of material were pasted on the tip of the sensors in order to simulate different sensations. A customised glove that exposed the thumb, fore finger and middle finger of the participants was used to allow the sensors to be firmly intact with the fingers and stagnant on the palm at all times. A wrist strap was used to fasten on the participant's wrist to ensure that the sensor positions were well maintained. Figure 2 shows the complete setup of the sensors.

Each participant was required to pinch every knob with the 3 commonly used pinch techniques, as identified by Smith and Benge (1985). The knobs were to be twisted using both clockwise and counterclockwise torque directions. Participants were also required to use all the pinch techniques under the conditions of both reduced and increased sensation.

The pinch force data were then recorded through the sensors and transferred to the statistical software Minitab 16 for further analyses. The analysis of variance (ANOVA) was used to determine if pinch force was significantly affected by tactile sensation, with reference to the p-value indicator. If the p-value is shown to be less than 0.05, the relationship would then be considered significant.

Results

Table 1 shows the ANOVA results on the significances of tactile sensation effects on pinch force. Based on the results for both the loaded and unloaded conditions, it appears that pinch force is significantly affected by sensation ($p<0.05$).

Figure 3a and b show the factorial plot result for the effects of tactile sensation on pinch force for the loaded and unloaded conditions. The results of the loaded condition in Fig. 3a suggest that the mean pinch force exerted with reduced sensation is 82.3267g (highest), which decreases by about 9.85% with the application of increased sensation to a mean pinch force of 74.2158g (lowest). The results of the unloaded condition in Fig. 3b similarly suggest that the mean pinch force exerted with reduced sensation is 81.7836g (highest), which decreases by about 9.81% with the application of increased sensation to a mean pinch force of 73.7593g (lowest).

Discussion

The preceding results are consistent with the findings of other researchers who suggested that increased sensation reduces force and reduced sensation increases force (Enders and Seo, 2011; Huysmans *et al*., 2008). Reduced sensation may reduce the acuity of tactile information obtained with the fingers and cause a reduction in friction between the fingers and the object, leading to a tendency to exert higher grip forces (Huysmans *et al*., 2008).

Researchers also found that individuals exert lower forces when gripping high-friction surface objects compared to low-friction surface objects (Enders and Seo, 2011; O'Meara and Smith, 2001). Researchers argue that individuals with less skin-object slippage apply less force when gripping high-friction surface objects compared to low-friction surface objects (Enders and Seo, 2011; O'Meara and Smith, 2001). It is also posited that reduced sensation lowered the requirement for precise coordination of multiple muscles involved in the pinch (Enders *et al*., 2010), causing participants to focus on pinching with greater force in order to avoid skin-object slippage.

The findings from the preceding studies appear to be consistent with the results shown in Fig. 3a and b. The results show that the average pinch force exerted for reduced sensations is higher than the pinch force exerted for increased sensations. Hence, participants may tend to exert higher forces on low-friction surfaces compared to high-friction surfaces.

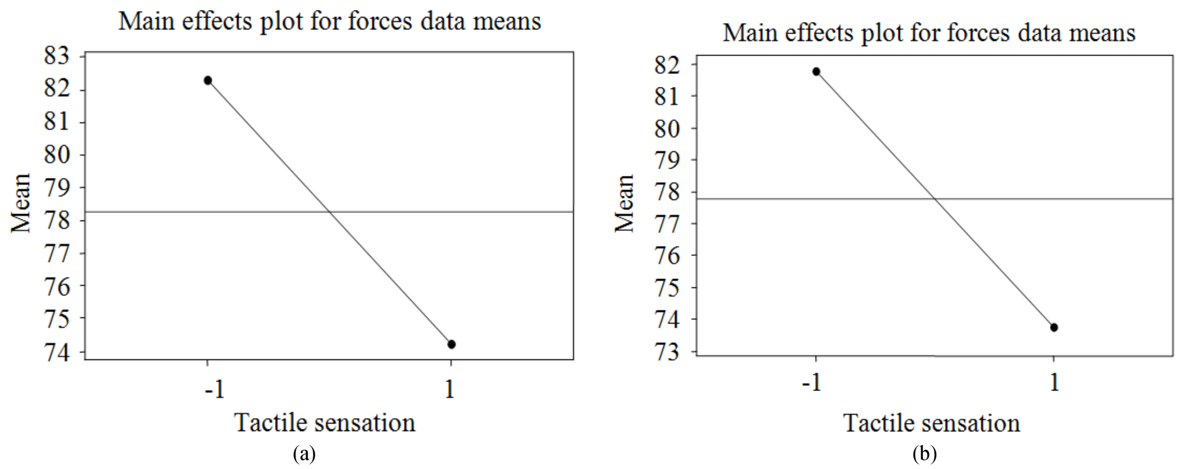

Fig. 3. Factorial plot of tactile sensation (a) Loaded (b) Unloaded

Table 1. Significances of tactile sensation effects on pinch force

Factors	Significance for loaded condition, *p*	Significance unloaded condition, *p*
Sensation	0.000	0.000

Conclusion

In this study, it was found that pinch force generated for a loaded and unloaded structure is significantly affected by tactile sensation. The average pinch force exerted for reduced sensation is higher than the pinch force exerted for increased sensation. This is due to the reduced friction experienced during the pinch activity and the increased possibility of skin-object slippages, which caused participants to voluntarily increase their force exertion to avoid these slippages to happen.

This study enhances the knowledge of the effects of different sensations on pinch force. With these findings, designers can potentially design objects that are operated with pinch grips to be safer and more suitable for manual tasks. Furthermore, surface textures of various knobs (such as dimmer switches, oven knobs, control knobs) can be redesigned to be safer (by perhaps opting for increased sensation) so that the force requirements are not too high. The preceding suggestions can potentially improve safety and eventually reduce the risk of injuries and musculoskeletal disorders.

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Author's Contributions

Poh Kiat Ng: Designed the research plan and experimental design. He conducted the data analysis and worked with writing the manuscript. He is also the leader of this research project.

Kian Siong Jee: Worked on the experimental setup, pilot experiment and actual experiments of this research. He contributed to the writing of this manuscript. He is also the co-project leader of this research.

Adi Saptari: Assisted in the data analysis of the study. He also contributed to the writing of this manuscript's introduction and literature review on pinch force.

Chiew Yean Ng: Contributed in providing facts and research information on the prevalence of hand-related injury cases in local hospitals. She also contributed in writing the literature review and findings related to musculoskeletal disorders and hand anatomy.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all other authors have read and approved the manuscript and no ethical issues involved.

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