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Research article

Effects of water immersion on sensitivity and plantar skin properties

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ABSTRACT

Skin, as the largest organ of the human body, has various important functions, like protecting from dehydration or preventing the intrusion of microorganisms. Certain external factors have been shown to negatively influence skin functions. One of those factors is long-term (several hours) exposure to liquids, such as water, leading to skin softening. This study aimed to examine whether detrimental effects, such as skin softening, already exist after short-term water exposure. Furthermore, we investigated whether cutaneous sensation is altered by short-term water exposure. Thirty healthy subjects participated in this study (23.1 ± 2.5yrs, 173.7 ± 8.5 cm, 67.5 ± 9.8 kg). First, vibration perception thresholds (VPTs; 200 Hz), the skin´s elasticity (logarithmic decrement), and the skin´s mechanical deformation resistance properties (durometer readings) were measured at the plantar aspect of the hallux and heel of both feet (pre). Subsequently, one randomly chosen foot was immersed in water (45 min; water temperature adjusted to the foot pre temperatures). The contra-lateral foot remained untreated and out of the water. After the intervention, all three above-mentioned parameters were measured again in the same manner (post). Inferential statistical tests to detect differences regarding elasticity, durometer readings, and VPTs were performed based on logarithmically transformed data (natural logarithm). VPTs did not show significant differences. However, an overall increased elasticity and a softening effect of the skin were evident due to the water exposure at both anatomical locations. This study showed that 45 min of water exposure induces changes in plantar skin properties similar to the long-term effects described in other studies. Most importantly, the short-term water exposure resulted in a softening effect, which may affect skin perfusion in a negative manner. This may facilitate skin irritations and even future ulcer formation. We also showed that changes in mechanical skin properties induced by water exposure did not influence plantar cutaneous sensation. The findings of this study are especially relevant for people with impaired skin recovery mechanisms and highlight the importance of keeping skin dry, particularly in people who are bedridden.

1. Introduction

Skin, the largest organ in the human body, is responsible for various functions, like preventing the intrusion of microorganisms and protection from dehydration [1]. Skin also contains various sensory receptors, e.g. free nerve endings and cutaneous mechanoreceptors. These receptors allow us to actively interact with the environment. In particular, the importance of plantar cutaneous receptors on posture is well established, e.g. [2]. Skin sensitivity decreases with increasing age [3] or with disease, such as diabetes mellitus [4]. This negatively impacts balance [4], and may facilitate ulcer formation [5]. Free nerve endings provide information when harmful stimuli are delivered toward the skin. In healthy subjects, noxious stimuli usually result in nociceptive reflexes [6]. In people with a severely reduced protective function of the skin, nociceptive reflexes may be slower or even be missing. Consequently, mechanical (or heat) stimuli applied toward the skin may be missing due to receptor and/or nerve damage. Since skin recovery mechanisms are impaired in those patients, skin ulcers may be the consequence which lead to considerable restrictions of daily activities.

Not only plantar sensitivity, but also plantar mechanical properties of the skin have been investigated. There are studies examining plantar skin mechanical properties (e.g. [7]), plantar tactile sensitivity (e.g. [8]), or both (e.g. [9]). Lin et al. [7] found that plantar shear stiffness is highest at the level of the skin, and decreases with increasing depth of the tissue. There have also been questions about how plantar skin sensitivity may be influenced by various skin mechanical properties. It was shown that plantar sensitivity [8,10] and skin mechanical properties [9] are different across the foot sole, but skin sensitivity does not significantly correlate with skin mechanical properties [9]. Hence,

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changes in skin sensation cannot (solely) be attributed to differences in skin mechanical properties, such as hardness or thickness [9].

Skin contact with various liquids was also identified as a factor which may influence different skin properties [11], and eventually lead to skin maceration [12]. Not only hot substances or chemicals exhibit detrimental effects, but also urine, perspiration, or even water [13–15]. The latter was found to soften the skin and increase the vulnerability of underlying blood vessels to pressure-induced blood flow reductions [13]. It is possible that the skin softening effect co-exists with the reduced blood flow observed. In other studies, increased abrasion damage, skin irritations, which may result in ulcer formations, or other damage were found when subjects were repetitively exposed to urine or perspiration [14,16–18]. Such findings may play an important role for people who are bedridden some or all of the time. In particular, it was presumed that bed rest of 14 days resulted in changes in pressure sensitive cutaneous receptors [19]. However, we found no studies examining short-term effects of water exposure on skin properties. Furthermore, ulcer formation may also be promoted by decreased skin sensitivity, where noxious (mechanical) stimuli are not adequately perceived. Regarding skin sensitivity, vibration perceptions thresholds (VPTs) have been identified as a reliable parameter to identify diabetes patients and even to identify the risk of plantar ulcer formation [5,20].

It was also shown that VPTs depend on skin temperature [8,21,22]. To cool the skin, including its receptors, protocols often include water exposure. Long-term water exposure leads to skin softening [13,18], which additionally may dampen vibratory stimuli, resulting in increased VPTs. Again, we found no study which has explicitly examined the effects of water immersion on plantar VPTs. If such an effect were proven, the common interpretation that reduced VPTs occur after skin is cooled by water may not be that definite, and the indicating contribution of VPTs to detect risks for ulcer formation may be biased. Therefore, this study examined the effects of short-term plantar water exposure on VPTs and various mechanical skin properties. We hypothesized decreased skin sensitivity, increased elasticity, and decreased mechanical skin deformation resistance following short-term exposure of the plantar foot to water.

1.1. Material and methods

1.1.1. Subjects

Thirty subjects (13♀, 17♂) participated in this study (mean ± SD: 23.1 ± 2.5yrs, 173.7 ± 8.5 cm, 67.5 ± 9.8 kg), and were free of lower extremity pain and injuries for at least 6 months prior to testing. Subjects were also free of neurological diseases like diabetes mellitus, neuropathy, or Parkinson´s disease. They showed normal plantar skin properties and no signs of open wounds, ulcers, impurities, or reddened, itchy, dry, or rough skin. Participants were informed about the purpose of this study. They gave their written informed consent and were free to withdraw from the experiments at any time. This study was conducted according to the recommendations of the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Behavioural and Social Sciences of the corresponding university.

1.1.2. Instrumentation

Plantar, water, and room temperatures were measured using a digital type-K-thermocouple (PeakTech 5135, Germany). To assess plantar skin sensitivity, VPTs were measured using a Tira Vib vibration exciter (model TV51075, Germany), powered by a Voltcraft oscillator (model FG 506, Germany). The vertical movement of the vibration exciter's contactor (diameter 7.8 mm, 2 mm above the surrounding aluminum platform, see [8,23]) was laser-calibrated to obtain direct readings of the vibration amplitude. To reach the subjects´ plantar skin, the contactor protruded through a hole in a heatable aluminum platform, which was adjusted to the subjects´ plantar temperature to avoid plantar skin temperature fluctuations. This was necessary, since skin temperatures are known to influence skin sensitivity [8,10,22]. During the measurements, subjects evenly placed their feet on top of the aluminum platform which functioned as the footrest. The frequency of the vibrating contactor was 200 Hz, which is known to be within the optimal stimulus range to elicit fast-adapting mechanoreceptors of type II (FA II, Vater-Pacini-corpuscles) [24]. The vertical force applied from the subjects´ feet toward the contactor was monitored via a force transducer and kept within a range of ± 0.5 N.

The MyotonPRO device (Myoton AS, Estonia) and a durometer (AD-100-OO, Checkline Europe, Germany) were used to assess mechanical properties of the plantar tissue. The handheld myoton device consists of an impactor (diameter approx. 3 mm) which touches the skin in five consecutive repetitions per trial (pre-compression 0.18 N, impulse force 0.4 N, duration 20 ms, respectively). The myoton analyses the naturally damped oscillation following the deformation caused by each impulse. The logarithmic decrement (log D) of the natural oscillation was used to characterize tissue elasticity. Since the elasticity is inversely proportional to the log D, tissue elasticity increases as log D decreases [25].

Furthermore, a durometer (Shore OO) was used to assess the skin´s mechanical deformation resistance properties, often mistakenly referred to as skin hardness. This handheld device was applied perpendicularly with respect to the anatomical location. Based on the probe´s penetration depth, the analogue scale of the device (shore scale range from 0 - softest to 100 - hardest) provided arbitrary units, which were sampled as measurement results.

1.1.3. Testing procedure

Before the tests, each subject acclimatized to the room temperature (23 ± 2 °C, EN ISO/IEC 17025) for 10 min (without the feet touching the floor). Afterwards, the participants´ right or left foot was randomly assigned as either control (CF) or intervention foot (IF). Anatomical locations were marked with a pen.

First, baseline measurements were performed at the plantar heel and hallux (middle point) of both feet prior to the intervention (pre). Regarding VPTs, subjects were in a quiet room wearing noise cancelling earphones (Quiet comfort 20i, Bose, USA) to avoid distractions during the measurements. All participants were in a sitting position with an ankle, knee, and hip angle of approx. 90°. They rested their arms on top of their thighs, close to the abdomen. Subjects were instructed to sit standardized but also comfortably to be able to concentrate on detecting the vibration stimuli. VPTs were measured similar to a Method of Limits approach as introduced by Mildren et al. [26]. In total, three VPT trials were collected at the heel and hallux (barefoot) of both feet. Plantar temperatures (PTs) were also measured at the heel and hallux of both feet. For log D and durometer readings, subjects were in a prone position with their lower legs and feet slightly elevated to approx. 60° by adjusting the footrest of a common patient couch. This enabled the myoton and durometer to be operated comfortably and accurately (vertical alignment with respect to anatomical location, no foot movements). Three trials were collected at each anatomical location of both feet.

Second, a bowl of sufficient diameter was used to perform the water intervention for IF. Pre PTs (mean of hallux and heel temperatures) were used to adjust the water temperature to avoid discomfort and temperature-related changes in VPTs. IF was immersed up to the ankle and the intervention lasted 45 min for each participant. Meanwhile, water temperature was monitored and warm water was added to keep temperatures constant throughout the intervention. Subjects sat with the CF resting next to the bowl on top of insulating material to prevent temperature changes. After the intervention, the IF was removed from the water and immediately dried using a towel.

Third, all measurements (PTs, log D, durometer readings, and VPTs) were repeated after the intervention (post) as described above. Anatomical locations were randomized, but not the order of measurements.