

Holes in wrist patches improve wearing comfort

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Abstract

Purpose – The purpose of this paper was to investigate whether small holes in an impermeable patch at the wrist improve perceived comfort during exercise.

Design/methodology/approach – Nine male participants participated in this study. During the experiment, participants cycled 60 W in a hot room (35°C, 30 percent relative humidity) while an impermeable 20 cm² patch was located on the ventral side of one wrist and at the same time a patch of identical shape with 5 mm diameter holes (17.7 percent uncovered) on the other wrist. The participants could not see the patches. Participants were forced to choose which patch they perceived as more comfortable. Chest and arm skin temperature, thermal comfort, thermal sensation and wetness perception were assessed.

Findings – Participants preferred 5 mm holes over no holes ($p = 0.017$). Chest skin temperature ($p = 0.018$) but not arm skin temperature correlates with this preference. Thermal comfort, thermal sensation and wetness perception did not differ significantly between patches. It is concluded that patches with 5 mm holes are preferred over impermeable patches during work in the heat in particular when the torso skin is warm.

Originality/value – The wrist is a preferred location for smart wearables. Generally, wrist bands are made of air-impermeable materials leading to sensation of wetness and discomfort. This study has shown that manufacturers should consider to make small holes in their wrist bands to optimize wearing comfort.

Keywords Temperature, Thermal comfort

Paper type Research paper

1. Introduction

Instruments for measuring skin temperature, sweat rate or heart rate in sports are becoming increasingly smaller and more advanced. The wrist is often a preferred location for these instrumented patches. Since these patches are generally air-impermeable, the covered parts cannot be cooled by evaporation of sweat, which could possibly create a sensation of discomfort. This discomfort could distract the athlete from his or her performance. If holes were present in the patches evaporation may increase, leading to a lower skin temperature and eventually a better thermal comfort. In general, the electronic parts and connections in the patch are small enough to leave space for small holes. Although we realize that wrist patches



are not part of clothing, collars are often made of impermeable materials to guarantee a good seal around the wrist. These collars can be seen as a carrier of electronics in a similar way as separate patches.

The body's capacity to dissipate heat by dry heat loss is limited when a small difference in temperature between the body and the environment exists. Therefore a shift toward evaporation takes place to increase heat loss (Alber-Wallerstrom and Holmer, 1985; Maughan *et al.*, 2012). However, when not only ambient temperature but also humidity is high, it is difficult for sweat to evaporate from the bare skin, resulting in an increased skin- and core temperature, despite continuing sweat production (Alber-Wallerstrom and Holmer, 1985; Maughan *et al.*, 2012). Due to these increased temperatures, someone could experience thermal discomfort (Nakamura *et al.*, 2008). In addition, materials may influence comfort measures (Barker, 2002). Thermal comfort is an important factor for temperature regulation; it drives an individual to make behavioral changes to maintain normal body temperature and consequently provides a measure of how comfortable someone feels (Nakamura *et al.*, 2008).

A vast amount of literature is available on the effect of ventilation features and air permeability of fabrics on thermal comfort. In general, both have a positive impact on thermal comfort (Chan *et al.*, 2017; Chen *et al.*, 2014; Ho *et al.*, 2011; Sun *et al.*, 2015). Subjective comfort scores seems to correspond well with physiological measurements as skin temperature (Chen *et al.*, 2014). Even though clothing covers larger areas of the body, it is expected that the same principle holds true for wrist patches. As the skin of the forearm has between 159 and 252 active sweat glands per cm^2 on average (Randall, 1946; Taylor and Machado-Moreira, 2013), making holes in wrist patches will set free a certain amount of sweat glands. The holes allow for more evaporation with a relatively larger cooling effect. This might in turn have its effects on comfort measures.

To our knowledge, no literature is available answering the question whether holes in wrist patches will lead to more comfort. In the present study, temperature sensations were carefully monitored and being measured using three subjective scales: thermal comfort (ISO 10551, 2001), thermal sensation (ISO 10551, 2001) and wetness perception (Olesen and Brager, 2004). All three sensation scales relate to total comfort. It is thought that the subjective ratings are influenced by the wrist patch because the human body is able to distinguish relative temperature differences between 0.2 and 0.4°C on the forearm (Stevens and Choo, 1998). Evaporation of sweat may cause this decrease in skin temperature at the location of the holes. Second, local sensations on the forearm correlate with whole body thermal sensations (Choi and Yeom, 2017). Based on the above we, therefore, hypothesized that patches with holes will feel more comfortable than patches without holes. We consider this possible preference to be related to the subjective rating scales. Furthermore, we expect the skin temperature of the forearm to correlate well with the rating scales.

2. Methodology

2.1 Participants

Nine healthy males (age 20.6 ± 0.5 years; height 188 ± 8 cm; body mass 80 ± 6 kg, body surface area (BSA) $20,533 \pm 350 \text{ cm}^2$) with no history of sensory-related disorders volunteered to participate in this study. The protocol was approved by the ethics committee of the Faculty of Behavioural and Movement Sciences of the Vrije Universiteit Amsterdam. All participants gave their written informed consent for participation and filled in an anamnesis form after explanation of the experimental protocol, testing conditions and apparent risks.

2.2 Design

The design of the present study was based on the simultaneous application of two types of polyurethane air-impermeable patches on both wrists: without any holes or 5 mm in diameter

holes (Figure 1(a) and 1(b)). The patches were 0.5 mm thick. The average total surface area of each patch without holes was 20.0 cm² (length 7.5 cm, width 4.0 cm). There were 18 holes with 5 mm diameter (= 19.6 mm²) in the patches with holes. This equals an average surface area of $18 \times 0.196 = 3.53 \text{ cm}^2$ (17.7 percent open area). Since there are about 1.6–2.5 sweat glands per mm² on the wrists (Randall, 1946; Taylor and Machado-Moreira, 2013), patches with holes with a diameter of 5 mm will probably set free around 32 sweat glands to the environment. The holes were hexagonally arranged and equally distributed. During the experiment two patches were attached to the ventral side of both forearms with rubber bands at the same time. The patch on one wrist was always different from the patch on the other wrist. The order was randomized. The participants had to choose which patch was more comfortable by answering the following question: “Which patch is feeling most comfortable at this moment?”.

The experiment was executed single-blinded to minimize expectations of the participants. Therefore the participants wore basketball dribble goggles (brand: T-REX-Basket) (Figure 2), preventing them to look down to the wrists.

One skin thermistor (skin temperature sensor, YSI 200 series, Yellow Spring Instruments, Yellow Springs, Ohio, USA) was attached 5 cm from the proximal ventral side of the right forearm, a second on the left part of the chest, in between the clavicle and the nipple. The thermometers were held in place with Fixomull (BSN Medical, USA). These location were chosen to asses local temperature near the wrist patch and to have a measurement of the skin temperature of the core of the human body.

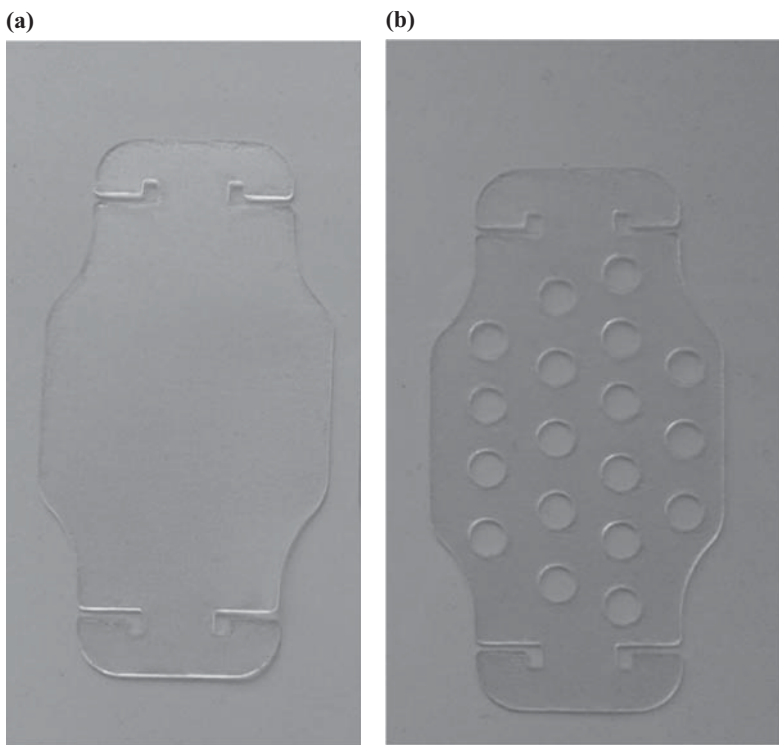


Figure 1.
The two types
of polyurethane
air-impermeable
wrist patches

Notes: (a) Patch without holes; (b) patch with 5 mm diameter holes

Because of the high rate of sweat loss, we had to ensure that participants did not dry out or that sweat production decreased during the experiment. Therefore, every participant had a drink bottle at his disposal. The water in the bottle was 35°C to avoid a cooling down effect of the body by hydration. The volume of the water in the bottle was measured before and after the experiment. Participants did not have to empty their bladders during the experiment. Sweat loss was calculated from the participant's body mass change and the volume of water the participants drunk during the experiment.

2.3 Experimental protocol

Participants arrived to the laboratory 30 min before the time scheduled for the test to allow preparation procedures. The participants then changed in shorts, sport socks and sneakers. They did not wear a shirt, since the sweat absorbed by the shirt sweat could influence the participants comfort. After providing informed consent, the participant's body mass was measured. Based on the weight and self-reported height of each participant, the BSA was calculated by using the Du Bois formula (DuBois and DuBois, 1915).

After preparation, participants entered the environmental chamber (set at 35°C, 30 percent relative humidity and air speed 0.2 m/s; Weiss Enet Custom made) and 10 min were allowed to get accustomed to the heat. During this period, participants were familiarized with the rating scales used to record thermal comfort, thermal sensations, and wetness perceptions: a five-point thermal comfort scale (1 comfortable; 2 slightly uncomfortable; 3 uncomfortable; 4 very uncomfortable; 5 extremely uncomfortable) (ISO 10551, 2001), an 11-point thermal sensation scale (−5 extremely cold; −4 very cold; −3 cold; −2 chilly; −1 slightly chilly; 0 neutral; +1 slightly warm; +2 warm; +3 hot; +4 very hot; +5 extremely hot) (ISO 10551, 2001) and an 11-point wetness perception scale (−6 extremely wet; −4 very wet; −2 slightly wet; 0 neutral; +2 slightly dry; +4 dry) (Olesen and Brager, 2004).

Thereafter, the participants were asked to start cycling for 5 min at 60 W with a frequency of 60 – 70 rpm on a cycling ergometer (Lode Excalibur Sport, type 911905, Groningen, The Netherlands) to warm up.

At the end of the warming-up, the participants were asked to rate their subjective scales again. Thereafter, participants cycled at the same workload and frequency as the warming-up (60 W, 60 – 70 rpm) (steady state) for a minimum duration of 40 min (maximum of 50 min). At the beginning of each period of two minutes, two different patches were applied to the participants' both forearms for 50 s in random order so that the subjects could get accustomed to the feeling of the patches on the skin. It is expected that the left-right effect is minimal as the human body has a substantial thermal



Figure 2.
T-REX Basket dribble
goggles that prevented
participants to be able
to see the patches
on their wrists

symmetry for skin temperature (Niu *et al.*, 2001; Vardasca *et al.*, 2007). During this period, the positions of the patches were not altered. At the end of these 50 s, participants had to choose which patch they did prefer. During the experimental test, participants were asked to assign a score to their thermal comfort, thermal sensation and wetness perception every 5 min approximately. Thereafter the patches were removed and the wrist was fully exposed to the local atmosphere for at least 1 min, to enable the participant's comfort – regarding the wrist – to return to baseline levels before the next combination of patches was applied. This sequence was repeated 12 times per participant to improve the statistical power of the experiment.

At the end of the experiment, the thermometers were disconnected from the participant before leaving the environmental chamber. Thereafter the weight of the participant and drink bottle was measured.

2.4 Statistical analysis

Parametric data were tested for normality using the Shapiro-Wilk test. The choice for most comfortable patches was analyzed by a one-sample *t*-test. The one-sample *t*-test determines whether the mean of a sample differs significantly from the population mean, which is also called the test value. In this study the test value is set at 50, because this is the chance level of choosing one patch, out of two, as being more comfortable. The mean thermal comfort, mean thermal sensation, mean wetness perception and mean skin temperatures (chest and forearm) were analyzed by a one-way ANOVA with 'time' as the independent factor. Spearman's ρ correlations were used to investigate the degree of association between variables. All data were analyzed using SPSS Statistics 25 (IBM Corporation, Armonk, NY, USA). In all analyses, $p < 0.05$ was used to establish significance.

3. Results

3.1 Changes in subjective ratings, weight loss and mean skin temperatures over time

All data were normally distributed. The results show that the subjective rating (thermal comfort, thermal sensation and wetness perception) changed significantly over time. Mean thermal comfort and thermal sensation increased significantly over time ($p = 0.012$) and ($p = 0.017$), respectively (Figure 3(a) and 3(b)). Mean wetness perception decreased significantly over time ($p = 0.000$) (Figure 3(c)). In short, this means that scores on all three subjective ratings became worse during the experiment. Furthermore, all participants lost weight as a consequence of sweat secretion (mean 0.71 ± 0.2). Neither the average skin temperature of the chest nor of the forearm decreased significantly over time ($p > 0.05$) (Figure 3(d) and 3(e)).

3.2 Percentage patches chosen

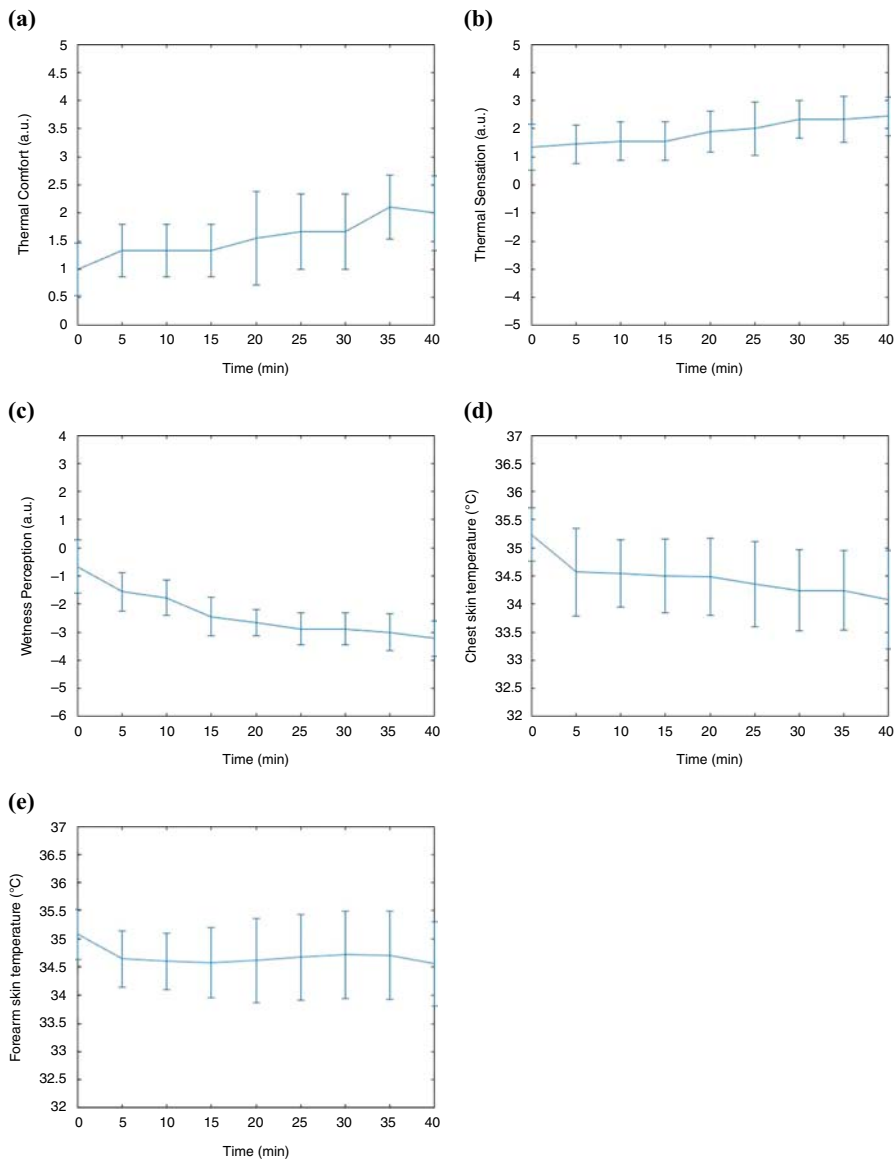
The percentage of the chosen patches was analyzed and different from chance level (50 percent) ($p = 0.017$; one-tailed). 60 percent (95% confidence interval was 5 percent) choose the patches with holes to be more comfortable (Figure 4).

3.3 Correlation patches chosen and rating scales

The means of the rating scales for thermal sensation, thermal comfort and wetness perception were analyzed against the choice of patches made during the trials using correlation analysis. No significant correlation was found between a rating scale and the choice of the patch ($p > 0.05$).

3.4 Correlation patches chosen and physiological measures

There was a significant correlation between mean chest skin temperature and the percentage of patches chosen, $r_c = 0.76$, $p = 0.018$. The correlation between mean forearm skin temperature and percentage of patches chosen was non-significant.



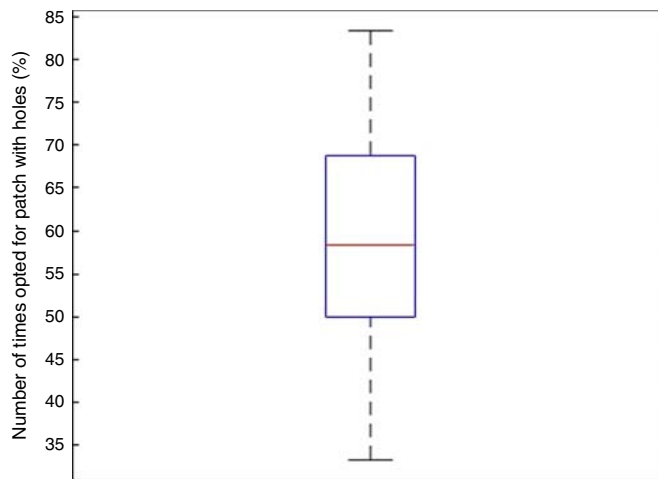
Notes: (a) Mean thermal comfort; (b) thermal sensation; (c) wetness perception; (d) skin temperature of the chest; (e) and forearm over time. Values on the x-axis reach to 40 because each trial took at least 40 min. Data shown include error bars (95% confidence interval)

Figure 3.
Mean subjective
ratings and skin
temperatures (°C)
over time

4. Discussion

The aim of this study was to investigate whether holes in wrist patches could make a difference in wearing comfort. One part of the hypothesis, mentioned in the introduction, was confirmed: patches with holes were judged as more comfortable than the patches with no holes. However, this was not related to forearm skin temperature and the subjective rating scales.

Figure 4.
Number of times
chosen for the patch
with holes



The participants sweated profusely during this experiment, inducing a shift in thermal comfort from comfortable (1.00) to slightly uncomfortable (2.00) (Figure 3(a)). Similarly, thermal sensation increased from slightly warm (1.33) to warm (2.44) (Figure 3(b)) as the experiment progressed. Wetness perception decreased over time (from -0.67 to -3.22) (Figure 3(c)), meaning that participants felt more wet at the end of the experiment. Chest and forearm skin temperatures slightly decreased over time (Figure 3(d) and 3(e)), presumably resulting from a cooling effect of the abundant sweating (Neves *et al.*, 2015). However, the skin temperature differences were non-significant and might also be due to the short acclimation period, resulting in an insufficient adjustment of the human body. The large scatter in forearm skin temperature (Figure 3(e)) could be due to the large regional variations in sweat rate on the arms (Smith *et al.*, 2007). If technology will be implemented in the patch, developers have to realize that many factors, such as pressure of the patch, can influence skin temperature measures (MacRae *et al.*, 2018) and subjective ratings.

The results showed a significant difference in preference from chance level for the patches with holes compared to patches without holes: 60 percent opted for the patches with holes. A significant correlation between chest skin temperature and the type of patch chosen was found (Figure 5).

This means that when participants have a higher chest skin temperature, they will rather opt for a patch with holes (Figure 5). It was shown that chest skin temperature decreased during the experiment (Figure 3(d)). Therefore, it is stated that at the beginning of exercise patches with holes are preferred. However, when exercise prolongs this preference becomes less relevant. Moreover, it is known that at 34°C surrounding temperature the core-skin temperature gradient has a rather stable average of about 2°C (Cuddy *et al.*, 2014). Since in our study the ambient temperature was set to 35°C one can assume that the chest skin temperature will have a similar stable offset from core temperature. Thus, chest skin temperature forms a reasonable estimate of core temperature when corrected for offset. Therefore, we observed an indirect relationship between core temperature and preference for patches with holes. Additionally, local sensations correlate well with whole body sensations (Choi and Yeom, 2017) whereas whole body sensations are in good relation with chest skin temperature (Bogdan, 2011). Altogether this indicates that the whole body sensation influenced the total comfort measure under the current experiment conditions.

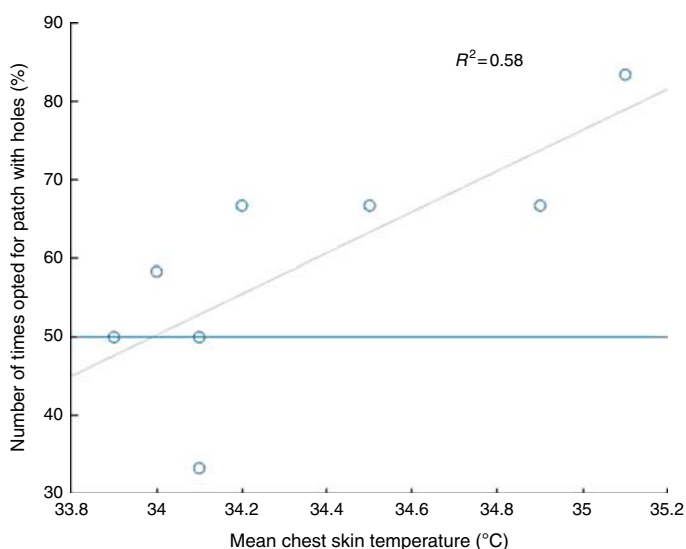


Figure 5.
Significant correlation
between preferred
patch and mean chest
skin temperature per
participant

We consider one possible explanation for the finding that patches with holes are preferred over patches with no holes at relatively high chest skin temperatures. A number of sweat glands will be exposed to the dry air surroundings in the patches with holes. The holes with a diameter of 5 mm cover an area of 20 mm² per hole and do contain at least a few sweat glands that are being exposed to the surrounding air. Because of the number of sweat glands that are being exposed, more sweat is capable to evaporate, resulting in higher cooling rates. Research showed that small mesh openings in clothing improved total heat loss and perceived comfort (Sun *et al.*, 2015). Hence, it makes sense that participants with higher skin temperatures tended toward the patches with higher cooling rates. However, Ho *et al.* (2011) demonstrated that, while heavily sweating, participants still experience clingy discomfort. This could be why “only” 60 percent in this study opted for the patches with holes. In the end, this study showed manufacturers should consider to punch small holes in their wearables or smart clothing products to improve wearer comfort.

Because during this study all participants were men, conclusions about the patches in relation to women cannot be made. Golja *et al.* (2003) found women to be more sensitive to warm and cold stimuli than men. Further research should investigate the effect of holes in patches with women as participants. In addition, a 50 s period to decide whether one patch is most comfortable is relatively short compared to the time wearables are used in sports or daily life for example. Consequently, future research should focus on longer investigation periods. Third, no conclusion can be drawn about the best size of the holes in impermeable wrist patches. Therefore, it is recommended to examine patches with different hole sizes.

5. Conclusion

We conclude that significant differences occurred in preference for patches with 5 mm diameter holes and patches without holes during work in the heat. Participants' chest skin temperature is related to the selected patch in contradiction to ones perceived thermal comfort. Therefore, it is recommended to punch holes of 5 mm circumference in impermeable patches to reduce thermal strain experience, especially in participants with a high chest skin temperature.

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