COOLING OF FINGER PAD TOUCHING DIFFERENT MATERIAL SURFACES

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INTRODUCTION

There has been comparatively little physiological research reported in the literature, regarding the contact cold exposure conditions. Havenith et al. (1) studied the responses of subjects gripping cylinders of different materials at -10 and 10 "C. The present investigation was designed to study the relationship between the change of contact skin temperature and the duration of contact on different material surfaces at different temperatures under a certain finger pressure.

METHODS

A total of 25 subjects (12 female and 13 male, 21 to 47 years of age) volunteered. Aluminium, plastic and wood materials (heat conductivities 220, 1.9, and 0.35 W/m^2 K, respectively) were cut into 110 x 110 x 110 mm square cubes with a polished surface. The cubes were put in a small chamber (770 x 400 x 400 mm) with the air temperature of -14, -5 and -1 °C for aluminium and -20°C for plastic and wood for sufficiently long time to equilibrate with the environment. The subject introduced his or her right hand into the chamber and pressed with three fingers on the material surface with a force of 9.81 N (1 Kp). The contact skin temperature on the middle finger pad was continuously monitored by a copper-constantan thermocouple with adiameter of 0.2 mm. The sensor and the wire was attached to the finger so that the sensor itself was not covered by any tape or adhesive film. To avoid any cold injury, cold exposure was stopped when the subject felt very uncomfortable.

The individual cooling curves from the registration of the contact skin temperature was subsequently analyzed as being a modified Newtonian cooling curve (2, 3).

$$T_{(t)} = T_{end} + (T_{sk} - T_{end}) . (A . e^{-\frac{t}{\tau_1}} + B \cdot e^{-\frac{t}{\tau_2}}) \text{......................(1)}$$

$T_{(t)}$: skin temperature on time t; T_{sk}: resting skin temperature; T_{end}: final skin temperature: t: cold exposure time; 7 :time constant of the cooling process.

The statistical analysis was carried out with the computer program Systat 5.1 for the Macintosh. Student's T test was used to analyze differences betwen mean values.

RESULTS

The table shows the avenge and the standard deviation of the constants in formula (1).

Objects	-1°C AL.	-5°C AL.	-14°C AL.	-20°C P.	-20°C W.
Samples	18	18	12	19	19
τ_1	0.82±0.56	0.79±0.40	0.83M.61	1.04±0.99	1.72±1.37
72	35.4i16.0	24.M14.3	25.9±16.9	130.7i51.4	115.8f56.0
T_{sk}	30.3f3.97	29.6±3.7	30.2±4.99	30.3±2.9	29.3±3.5
T_{end}	0.7±1.0	-3.M1.3	-12.1f1.2	10.1±3.3	11.0±3.7
A	0.71±0.1	0.69±0.08	0.64±0.1	0.60±0.13	0.60±0.11
B	0.28M.1	0.30±0.08	0.3750.09	0.4M0.14	0.39i0.11

AL. aluminium; P. plastic; W. wood.

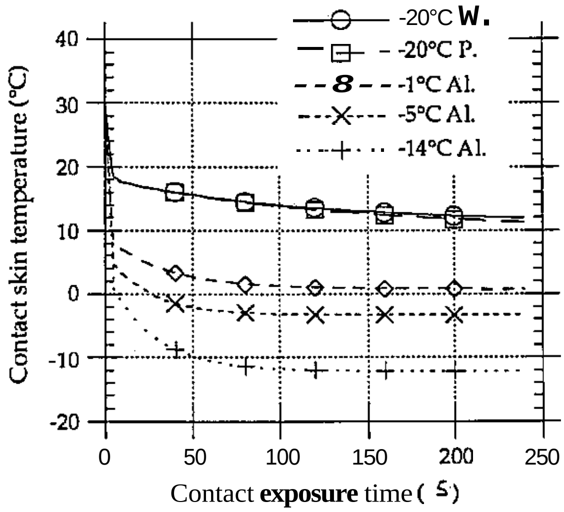
Gender had no significant effect on responses to the different conditions. The differences between τ_1 and τ_2 under each condition were significant (P<0.01). τ_1 from wood surface was significantly higher than that of the aluminium surface (P<0.05), but τ_2 from both plastic and wood surface were significantly higher (P<0.01) than from aluminium surface.

The estimated equations describing the change in contact skin temperature versus cold exposure time on different surfaces are shown as following. A graphical presentation of the relations are given below.

-1°C aluminium:	$T_{(t)} = 0.7 + (T_{sk} - 0.7).(0.71.e^{-\frac{t}{0.82}} + 0.28.e^{-\frac{t}{35.43}})$	(R=0.996);
-5°C aluminium:	$T_{(t)} = -3.31 + (T_{sk} + 3.31).(0.70.e^{-\frac{t}{0.79}} + 0.30.e^{-\frac{t}{24.0}})$	(R=0.997);
-14°C aluminium:	$T_{(t)} = -12.1 + (T_{sk} + 12.1).(0.64e^{-\frac{t}{0.83}} + 0.37 \cdot e^{-\frac{t}{25.9}})$	(R=0.987);
-20°C plastic:	$T_{(t)} = 10.1 + (T_{sk} - 10.1) \cdot (0.6 \cdot e^{-\frac{t}{1.04}} + 0.4.e^{-\frac{t}{130.6}})$	(R=0.997);
-20°C wood	$T_{(t)} = 11 + (T_{sk} - 11) \cdot (0.6e^{-\frac{t}{1.72}} + 0.39.e^{-\frac{t}{115.8}})$	(R=0.997);

DISCUSSION

Only one time constant was used to describe the contact skin temperature change in some (1) studies. In our study two time constants were required to accurately describe the temperature responses. The difference between them was statistically significant ($P<0.001$) under each contact exposure condition. No significant difference between τ_1 and τ_2 for the different temperatures of the aluminium surface was found, which indicated that the time constant was not strongly affected by the surface temperature. τ_1 should represent the contact skin temperalure reaction in the first few seconds of cold exposures. In this time, the superficial part of the skin surface cooled down very quickly and the effect was primarily on the skin-surface-sensor interface. τ_2 should represent the temperature change of deeper dermal structures and the core tissue of the finger, which are affected during the prolonged exposure.



The way of applying pressure and the pressure level between fingers and material surfaces are two factors that influence the contact skin temperature change. Havenith et al. (1) reported no contact skin temperatures below 0 °C at -10 "C conditions, despite having several subjects suffer from frostnip. The diameter of the sensor is another critical factor for the reliability of the measurements (4).

CONCLUSION

Two time constants were required to describe finger pad temperature change when contacting cold surfaces. For aluminum, contact temperature fell rapidly and approached asymptotically a value close to the material temperature. Apparently, more conservative values should be given for allowable lowest temperatures of touchable metal surfaces.

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