

Order-picking in deep cold – physiological responses of younger and older females. Part 2: body core temperature and skin surface temperature

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Abstract. So far, it was unclear to what extent working in deep cold-storage depots has an influence on female order-pickers body core temperature and skin surface temperature considering different age groups. Physiological effects of order-picking in a chill room (+3°C) and cold store (-24°C) were examined on 30 female subjects (Ss), classified in two age groups (20- to 35-year-olds and 40- to 65-year-olds). The body core temperature was taken every 15 min at the tympanum and the skin surface temperature was recorded continuously at seven different positions. Working in the chill room induced a decrease of the body core temperature up to 0.5K in comparison to the value at the outset for both age groups which could be compensated by all Ss during the breaks. Working in the cold store caused a decline up to 1.1K for the younger Ss and 1.3K for the older Ss. A complete warming-up during the breaks was often not possible. Regarding the skin surface temperature, working in the chill room can be considered as unproblematic, whereas significantly lower temperatures at nose, fingers and toes, associated with substantial negative subjective sensations, were recorded while working in the cold store.

Keywords: Field Study, Manual Material Handling, Age, Physiology, Severe Environmental Conditions

1. Introduction

Today's food supply system is built up to a great extent on refrigeration technology. In line with the trend of recent years, it is reasonable to assume that chilled and frozen food will experience a growing significance in the future. Due to this trend, the number of workplaces in cold-storage depots is also likely to increase in the future. As a cold environment may be a significant health risk factor (cp. [13,39]), work organisation as well as technical and constructional equipment in cold-storage depots should be designed on the basis of ergonomic measurements. Kluth et al. [19,20] noted that design changes within a cold-storage depot with chill room and cold store are feasible only to a minor extent due to management requirements and operational equipment. Thus, a sufficient number of scientific study

results (cp. [19,20,29,38]) show, that improvements related to workplaces in deep cold should focus on cold-protective clothing as well as duration and frequency of the warming-up breaks.

Order-picking in a cold storage depot and the associated deviation from the comfortable thermic zone may result in decreased physical (cp. [27]) and mental performance (cp. [30]). Physical performance, defined by Oksa et al. [28] and Faulkner et al. [9], is a combination of endurance, muscular fitness and physical skills. The cooling of the muscles affects the physical performance which then impairs most of its functional properties like power, force and velocity. The mental performance, which according to Pilcher et al. [31], plays an important role in the areas of orientation, safety, decision-making, work productivity and reactions to emergency situations is also influenced by a cold environment. According to a survey

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commissioned by Ramsey et al. [33], the ambient temperature has a statistically significant effect on the unsafe behaviour index (UBI). This is expressed through a U-shaped curve, with minimum UBI values occurring in the preferred temperature zone of 17°C to 23°C and an increase in the UBI for hot and cold environments. In addition to the negative impacts on the physical and mental performance, working in a cold storage depot can also have an impact on an individual's health. As stated by Oksa et al. [28] and Sormunen et al. [35], while working in these conditions, an increased muscular strain and other musculoskeletal complaints and symptoms are common. Mäkinen [22] further reported that everyday cold exposure may aggravate the symptoms of prevailing chronic diseases. Hassi et al. [14] mentioned that many types of chronic health problems such as cardiovascular diseases, respiratory symptoms, musculoskeletal diseases, peripheral circulation problems, and skin diseases, are associated with cold exposure. The heat loss, which may cause the complaints described, cannot completely be compensated by protective clothing and peripheral vasoconstriction (cp. [38]). Therefore, an increased energy expenditure is required, with the result that, due to its "heating effect", the physical strenuous work of manually handling of deep-frozen groceries is beneficial and necessary rather than disadvantageous (cp. [19,20]). According to Boothby et al. [5] increasing age is associated with a decrease of the physical capacity and the energy metabolism which leads to a poorer protection against cold. Two parameters which were utilised to monitor the comfortable thermic zone are the body core temperature and the skin surface temperature.

Work stress, surrounding temperature, time of day and in the case of female workers the menstrual cycle are the primary factors responsible for body core temperature changes. Work stress affects the core temperature – generally taken rectally - greater than the surrounding temperature. For work stress, the rectal temperature increases linearly with oxygen intake, whereby an increase of the oxygen intake by 1 liter (that is somewhat above the endurance level) also increases the rectal temperature by about 0.5K to 0.8K (cp. e.g. [2,25,34]). Time of day causes a body core temperature variation of about 1°C, while the female's menstrual cycle causes a variation of approximately 0.5°C. When it comes to core temperature changes during exposure to the cold the results of different studies vary widely. Hellström et al. [15] registered a decrease of 0.5K after an one-hour exposure to the cold, when reducing the surrounding temperature from 10°C to 0°C. In contrast, Forsthoff [10]

detected an increase of up to 1.0K compared to the value of the outset, after 50 minutes order-picking at -28°C surrounding temperature. Kleinöder [17] confirmed these results in laboratory tests simulating activities at -28°C. Kluth et al. [19,20], however, executed whole working-day tests in a cold store (at -24°C) with professional and non-professional male subjects. After two hours of order-picking the core temperature decreased up to 1.5K (younger subjects) and 2.2K (older subjects). Even if research findings so far indicate that an increase of the work performance and/or a sufficiently adapted increase of the warming insulation of the cold-protective clothes compensates for the substantial drops of the core temperature (cp. [4,10,40]), the results of Kluth et al. [19,20] demonstrate that this is possible only to a limited extent. One subject of the test series exhibited a resulting core temperature of approximately 34°C which, according to a German standard [44], approaches a value that poses a risk to health (cp. [20]). This German standard indicates that the core temperature can drop to 35°C without any health risk, but any further cooling down would be life-threatening.

The temperature variations in the peripheral tissues (body's outer structure) are greater than in the body core when changing the surrounding temperature. The reason for this is a strong decrease of the blood circulation in the skin during exposure to the cold. The result is an isolating shell of variable thickness, caused by radial and axial gradients formed in the peripheral layers. At low surrounding temperatures the shell is going to be thicker which causes a temperature drop at first only in the body periphery. In particular, the temperatures at the ends of the extremities change greatly with the surrounding temperature (cp. [1,18]).

The local cooling of the surface, especially of hands, feet and head may cause physical discomfort, a deterioration of the manual and physical capacity and cold injuries (cp. [43]). According to an international standard [42], the skin surface temperature is influenced by the heat exchange (consisting of convection, radiation and evaporation) as well as fluctuations of the skin blood circulation and temperature changes of the arterial blood which reaches the respective body part. The latter factor greatly depends of the entire heat balance, which is negative, if the protective clothing does not meet the IREQ (required clothing insulation). Experiments carried out in laboratories (cp. [6,12,17,24,26]) showed that the skin of hands, feet and face are most affected by cold exposure. Gavhed et al. [12] showed that an air tempera-

ture of -10°C (with wind speed of 0.2 m/s) led to a decrease of the nose temperature down to 10°C even when walking on a treadmill at 2.8 km/h. It should further be noted that the skin temperature of the nose decreased when the wind speed increased and also that higher exercise intensity (by increasing the incline of the treadmill) had a positive effect on the skin temperature. A field study, carried out by Forsthoff [10], which was already mentioned above, exhibits that the toes are also affected to a great extent when working in extreme cold conditions. Forsthoff registered a decrease of the toes skin temperature up to 16K compared to the value of the outset which could not completely be compensated during the warming-up breaks. While the skin temperatures of the torso could be influenced by variation of energy expenditure and thickness of the clothing, the temperatures of feet and toes could only be influenced by an improved protection against the cold through an increased insulation of the boots (cp. [10]). The above mentioned whole-working day tests, carried out by Kluth et al. [19,20], recorded an average skin surface temperature decrease of the nose down to $+15^{\circ}\text{C}$ during 2 hours exposure to the cold. The temperature decrease of the toes was smaller but continuous. While the nose and the fingers warmed up completely during the breaks, the toes only completely warmed up within a minimum of 20 minute warming-up break, and if the boots were taken off. Skin temperature sensors under the thick protective clothing (installed in the area of the kidney and shoulder) registered no substantial temperature changes. When comparing the results from Kluth et al. [19,20] with the results from Forsthoff [10] it can be concluded that only widely successful protective clothes can compensate for the potential negative health effects of working in deep cold.

2. Methods

Fifteen female subjects (Ss), each, in two age groups (20- to 35- and 40- to 65-year-olds; cp. Table 1) were asked to carry out whole-working day tests in order to assess whether order-picking in a cold-storage depot with chill room (approx. $+3^{\circ}\text{C}$) and cold store (approx. -24°C) is sustainable at any age for female workers in the long run. The Ss had to work under predetermined, realistic working conditions in a chill room and in a cold store with modified working phases with a duration of 80, 100, and 120 minutes,

The studies from Gavhed et al. [12] also suggest that increased energy expenditure can have a positive effect on the skin surface temperature. Therefore, the physical strain of order-pickers can also be seen as advantageous in the context of successful protection against cold regarding the skin temperatures, which is confirmed by studies of Imamura [16]. A decline of the skin surface temperature, especially in the hands and feet can lead to a loss of mobility, sensitivity and agility (cp. [41]). Referring to Fox [11] and Provins and Clarke [32] the temperature of the hands is clearly a limiting factor in the performance of manual tasks in the cold. Morton and Provins [23] and Stevens et al. [36] defined $8-10^{\circ}\text{C}$ as a critical hand and finger skin temperature for unimpaired tactile sensitivity, and $12-15^{\circ}\text{C}$ was defined as critical temperature for manual dexterity by Clark [7] and Dusek [8]. Besides the restriction in the performance of manual tasks, health problems like ankylosis can be the outcome of recurring exposures to the cold with low skin temperatures (cp. [3]). In order to create sustainable jobs which do not pose a substantial threat to health, it is necessary to optimize the cold protective clothing in combination with an appropriate combination of work time and warming-up breaks. Optimization however must be achieved in consideration of the features of the individual, as the factors that affect thermal responses are age, gender, fitness, health, pre-existing diseases and medication (cp. [37]). Nevertheless, Kluth et al. [19,20] made an important contribution to the age-differentiated assessment of the effects of working in the cold, but until now limited to male subjects. However, the female body has some different characteristics which create quite different conditions regarding working in the cold.

separated by identical warming-up breaks of 20 minutes, each, at about $+21^{\circ}\text{C}$. To achieve results that can be compared, the Ss had a work load adapted to the real job with an average of 1.6 tons (t) of goods to be order-picked within one hour (8t per day). During the whole working day, the body core temperature was taken at the tympanum every 15 minutes and the skin surface temperature was monitored continuously at 7 positions (cp. Figure 1).

In addition, parameters of the blood circulation (heart rate and blood pressure) and the energy metabolism were measured (cp. [21]).

During performing the tasks, the Ss had to wear cold-protective clothing (equal to the clothes worn by the professional female order-pickers). Adapted to the surrounding temperatures, in the chill room,

warm underwear, a pair of trousers, a thermo shirt, a thermo vest, a wool hat, knitted gloves and thermo-insulated shoes were used. In the cold store, the Ss were equipped with a cold-protective suit consisting of a thick jacket and long trousers which they had to

wear above their underwear, pullover and pair of trousers. Further protection against the cold was provided by thermo socks, fleece gloves, a wool hat and cold-insulating boots.

Table 1
 Characteristics of the female subjects, 15 each in the age group “young” (left part) and “old” (right part)

Ss “young”	Age [Years]	Height [m]	Weight [kg]	Ss “old”	Age [Years]	Height [m]	Weight [kg]
01	27	1.74	73	01	59	1.69	80
02	24	1.76	68	02	54	1.63	52
03	25	1.67	67	03	61	1.68	61
04	22	1.76	64	04	52	1.56	57
05	20	1.62	54	05	53	1.70	61
06	20	1.70	77	06	59	1.61	53
07	20	1.70	65	07	57	1.70	71
08	21	1.80	66	08	43	1.58	73
09	22	1.60	59	09	44	1.66	67
10	25	1.70	58	10	51	1.68	60
11	28	1.63	50	11	44	1.76	77
12	27	1.69	59	12	50	1.64	60
13	21	1.58	51	13	64	1.73	104
14	32	1.71	77	14	61	1.73	103
15	26	1.58	71	15	48	1.68	55
$\bar{x} \pm S_d$	24.0 ± 3.6	1.68 ± 0.1	63.9 ± 8.7	$\bar{x} \pm S_d$	53.3 ± 6.7	1.67 ± 0.1	68.9 ± 16.4

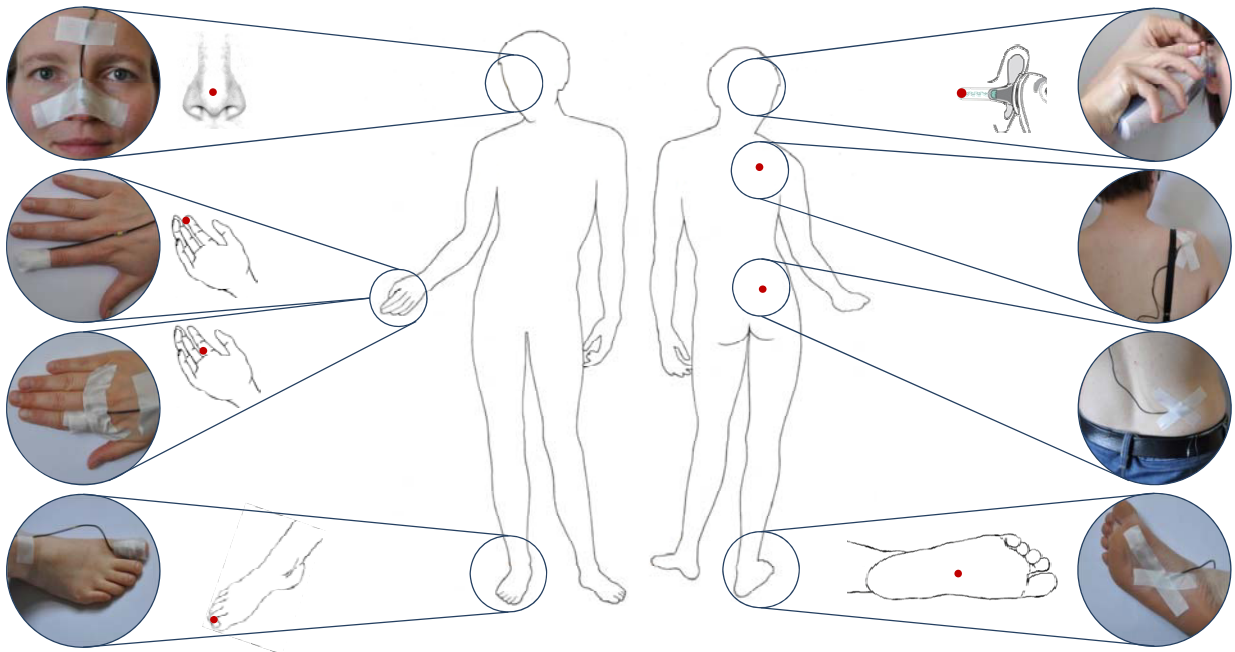


Fig. 1. Measuring points for the recording of the skin temperature (nose and 6 additional measuring points on the right part of the body) and the body core temperature (right ear)

3. Results

As can be seen from Figure 2, while working in the cold store at a surrounding temperature of -24°C , the core temperature taken with an ear thermometer at the tympanum every 15 min, differed by 1.1K (after the 80 min exposure to the cold) to 1.3K (after the 120 min exposure) in the age group of the 40- to 65-year-olds compared to the temperature at the outset (36.9°C). In the age group of the 20- to 35-year-olds (see white columns in Figure 2), after 80 min working in the cold at -24°C the core temperature dropped by 0.9K and 1.1K after 120 min working in the cold compared to the temperature at the outset (37.0°C). In both age groups, the temperature at the outset was often not quite fully reached after a 20 min warming-up phase. While working in the chill room, with a surrounding temperature of about $+3^{\circ}\text{C}$, the decrease of the core temperature was comparatively low. Figure 3 shows a maximum decrease of 0.5K from the value of the outset for both age groups in different working phases. Furthermore, the temperature at the outset was mostly reached from the Ss of both age-groups after a 20 min warming-up phase.

Figure 4 visualizes a considerable decrease of the skin temperature at the nose, which was exposed to

the cold without any protection. The temperature dropped on average to 15°C and 16°C for the younger and older Ss, respectively, while working 120 min in the cold storage depot at -24°C . The low temperature of the nose could be compensated very quickly during the warming-up breaks, supported by a more intensive blood circulation of the face after leaving the cold store. The temperature profile of the toe in Figure 4 showed a somewhat smaller but continuous decrease with a significant difference between the absolute average temperatures of both age groups.

The skin temperature of the fingertip (not graphically shown) exhibits a similar trend as the nose with average temperatures of approx. 20°C for both age groups. The sensor under the sole of the foot measured nearly constant temperatures throughout the entire working day. As to be expected, the temperature sensors in the area of the shoulder and kidney recorded inconspicuous values. Due to the thick cold protective clothing, the skin surface temperature decreased only slightly, and the value of the outset was reached after a very short time during the warming-up break.

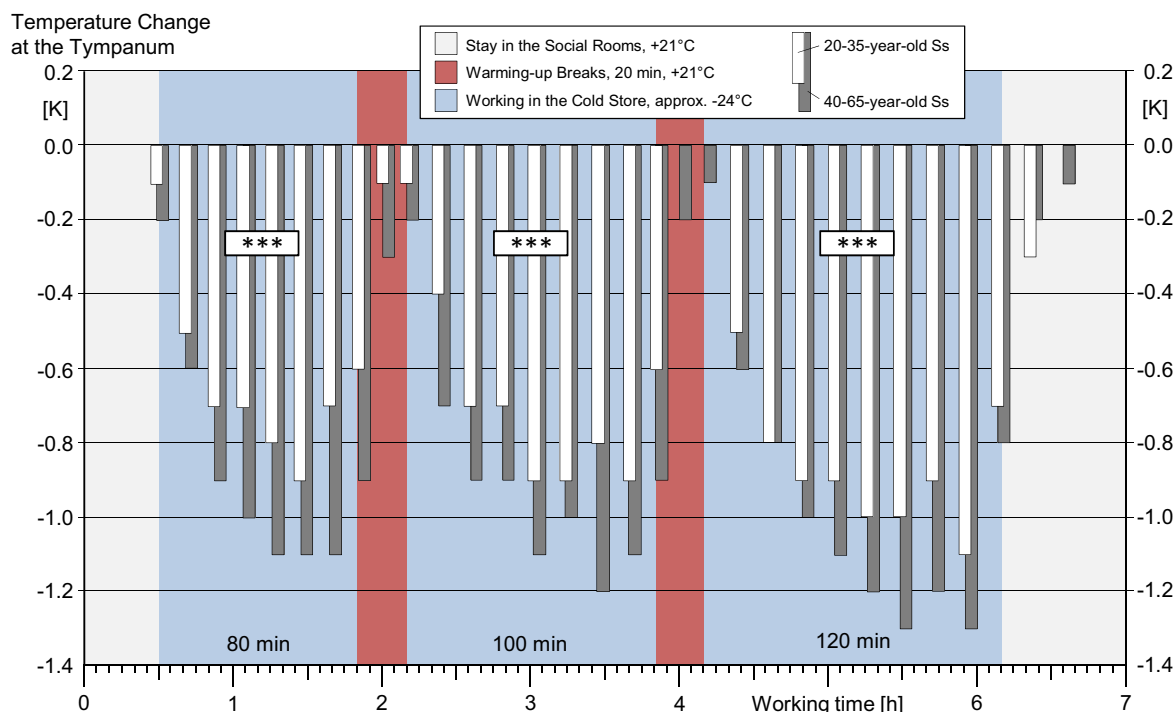


Fig. 2. Tympanum (core) temperature changes [K] of female order-pickers prior to, during and after cold exposures of 80, 100, and 120 min at approx. -24°C in the cold store. Means of 15 Ss in two age groups, each, with symbolic labeling of statistically significant differences of the two-sided t-test (-: $p \geq 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$).

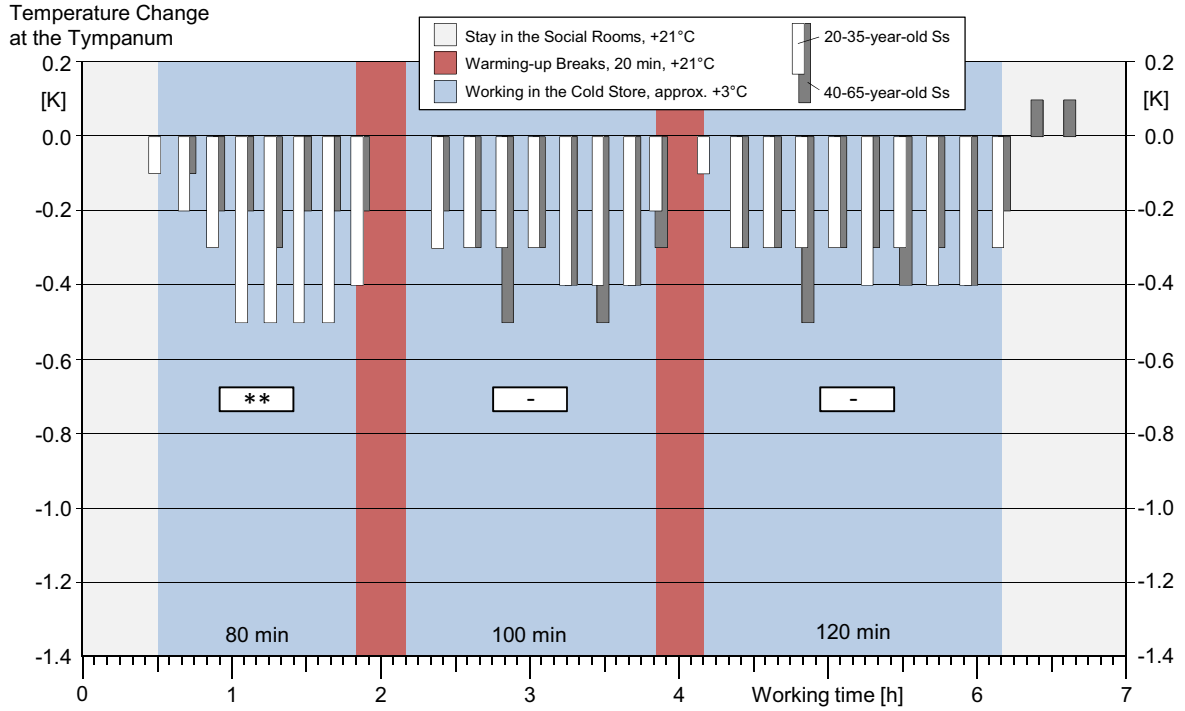


Fig. 3. Tympanum (core) temperature changes [K] of female order-pickers prior to, during and after cold exposures of 80, 100, and 120 min at approx. +3°C in the chill room. Means of 15 Ss in two age groups, each, with symbolic labeling of statistically significant differences of the two-sided t-test (-: $p \geq 0.05$, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$).

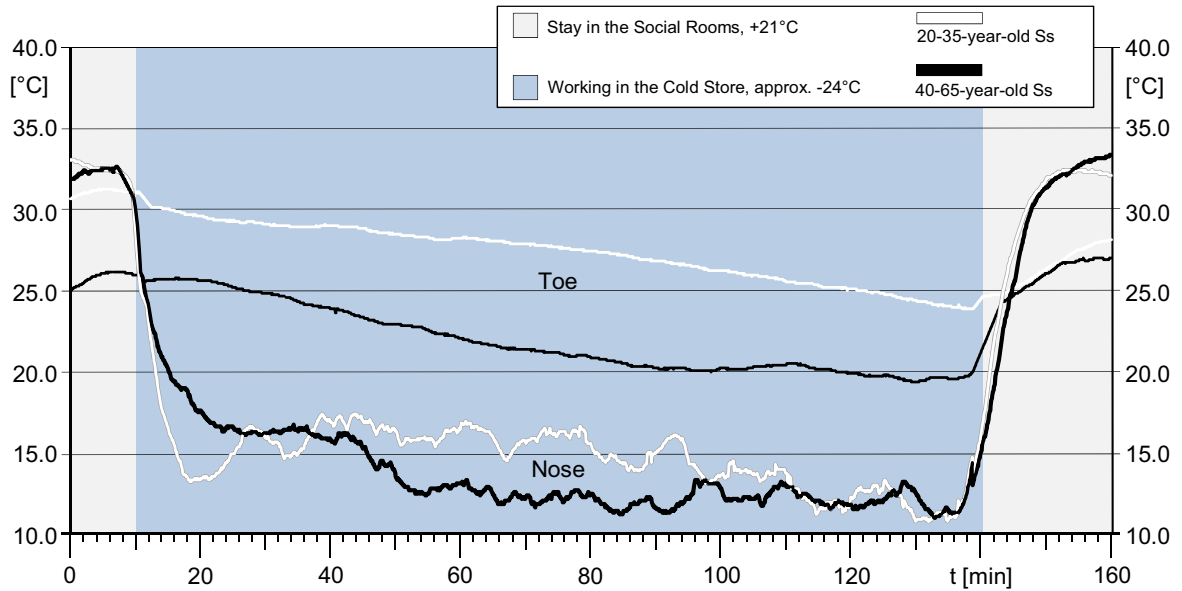


Fig. 4. Means of skin temperature [°C] at the nose and toe of 15 female Ss in two age groups, each, prior to, during and after a cold exposure of 120 min at approx. -24°C in the cold store.

4. Discussion

The results of the study show that despite the partly adequate cold protective clothing and the physical strenuous work of manually handling frozen groceries, working in the cold leads to significant decreases of the body core and skin surface temperature. On average the body core temperature of both age groups decreased to 35.6°C, but there were 7 individuals in the age group of the 40- to 65-year-olds whose temperature dropped under 35°C. None of these individuals reached their initial temperature after the 20-minutes warming-up breaks. 3 persons (all of them over 50 years old) showed a temperature drop under 35°C in all 3 working phases. Subject number 14 (age: 61 years, height: 1.73m, body mass: 103kg) exhibited in every working phase substantial decreases of 2.4K down to 34.1°C. According to a German standard [44] a health risk cannot be excluded if the body core temperature drops under 35°C. Therefore, questions have arisen whether this kind of work is practicable in the long run under today's working conditions in cold-storage depots. It is practicable for the chill room where no values were measured that pose a risk to health. The physiological responses to the cold exposure in the cold store, however, do not meet the requirements of this standard and more attention should be paid to an extension of the warming-up breaks within further surveys.

The skin surface temperature of the toes showed a slight decrease compared to the laboratory tests already mentioned in the introduction. A slight decrease was also determined by Kluth et al. (cp. [19,20]), suggesting that the physical activity of order-picking with increased blood circulation has a positive effect of the toes skin surface temperature. However, the skin surface temperature of the fingers and nose decreased very quickly and intensely after exposure to the cold. In individual cases, temperature values lower than 10°C were reached. The skin surface temperature of one subject's fingertip fell below 3°C within 20 minutes of exposure to the cold. This resulted in severe pain which persisted even after the warming-up break.

Even if the measured physiological responses indicate adequate protection against cold, the described individual cases show that the existing cold protective clothing and the working time in relation with the duration of the warming-up breaks is not sufficient for these persons.

5. Conclusion

The structure of the labour market is constantly undergoing change, away from fresh and home-grown towards chilled and frozen food, and its future trend is shown clearly through the development in recent years.

The working population – due to the demographic changes – will become older and even more women will be present in the workforce. In particular physically demanding work, which was a few decades ago only for men, is increasingly performed by women. Therefore, in the future more older female workers partake in physically demanding work under particularly difficult environmental conditions. Due to a decreasing physical capacity and energy metabolism of older humans and in particular women, this led to the assumption that this group must be protected in a special way when working in the cold. The results of this survey in combination with the findings of Kluth et al. (cp. [19,20]) however, show, that older females are not in a worse position regarding protection against cold compared to young males. Therefore, it is not necessary to create working conditions adapted on gender and age; rather an optimization should be conducted with the aim of a holistic employment protection. Primarily, this includes the optimization of the mix of working- and break-times as well as the cold protective clothing which do not provide an adequate protection against cold, for an indefinite period and for all body parts. Especially the cold-insulating boots and gloves need some improvements.

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