TNO Institute for Perception

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TNO-report IZF 1992 B-11
H.A.M. Daanen
W.A. Lotens

SYNCHRONISATION OF COLD INDUCED VASODILATION IN THE FINGERS OF TWO IMMERSED HANDS

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SUMMARY

In an attempt to quantify the contribution of central and peripheral mechanisms to blood flow in the hands during immersion in cold water, eight male subjects immersed their hands simultaneously (S) and five minutes after each other (NS) in water of 10°C. Starting 15 minutes after immersion of the first hand, a period of 32 minutes was used for an analysis of the temperature fluctuations on all finger tips. The mean Pearson Correlation Coefficient (PCC) of all combinations of finger temperatures was taken as an indicator for the amount of central/local influence.

The PCC did not differ between S and NS. The mean PCC was 0.63, which implied a greater central influence than in a previous investigation (Daanen & Lotens, 1992), in which the body heat content and water temperature was lower (PCC = 0.55). The substantial central influence was also shown by the variation in heat transfer of the hands to the water, which was 43% of the average fluctuation in finger temperature and only 31% in the previous investigation. It is supposed that central heat elimination is predominant when the core temperature surpasses a subject specific threshold, and that its influence decreases when core temperature and water temperature decreases.

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Instituut voor Zintuigfysiologie TNO
Soesterberg

Synchronisatie van door koude geïnduceerde vasodilatatie in de vingers van twee ondergedompelde handen

H.A.M. Daanen en W.A. Lotens

SAMENVATTING

Om de bijdrage van centrale en perifere mechanismen aan de doorbloeding van de handen tijdens onderdompeling in koud water te onderzoeken, hebben acht mannelijke proefpersonen hun handen gelijktijdig (S) en vijf minuten na elkaar (NS) ondergedompeld in water van 10°C. Een periode van 32 minuten, beginnend 15 minuten na onderdompeling van de eerste hand, werd gebruikt voor de analyse van de temperatuurschommelingen van alle vingertoppen. De gemiddelde Pearson Correlatie Coëfficiënt (PCC) van alle mogelijke combinaties van vingertemperaturen werd gebruikt als indicator voor de hoeveelheid centrale of perifere invloed. De PCC verschilde niet tussen S en NS. De gemiddelde PCC was 0.63, hetgeen een grotere centrale invloed betekende dan in een voorgaand onderzoek (Daanen & Lotens, 1992), waarin de warmteinhoud van het lichaam en de watertemperatuur lager waren (de PCC was 0.55). De substantiële centrale invloed was ook te zien in de variatie in warmteafgifte van de handen aan het water, die 43% bedroeg van de gemiddelde fluctuatie in vingertemperatuur in dit onderzoek en slechts 31% in het vorige onderzoek. Er wordt verondersteld dat centrale eliminatie van warmte belangrijk is indien de kerntemperatuur een persoon-specifieke drempel overschrijdt, en dat deze invloed afneemt naarmate de kerntemperatuur en water temperatuur afnemen.

1 INTRODUCTION

In a previous investigation (Daanen & Lotens, 1992) the Cold Induced Vasodilation (CIVD) pattern or "hunting response" of several locations on the skin of the immersed left hand was compared. The amount of correspondence was estimated by calculation of the Pearson Correlation Coefficient (PCC). It was shown that the PCC of neighbouring fingers of a hand immersed in water of about 5°C was much higher than fingers who were separated. This implies that CIVD can not be regarded as a purely local phenomenon. Moreover, neighbouring fingers sharing the same somatic nerves showed a higher PCC than those with different innervation. From these results it was concluded that a nervous component, probably the axon reflex, plays a role in the "hunting" response.

The possibility exists, however, that every finger exhibits a characteristic pulsating flow pattern triggered by the immersion in cold water. Due to similarities in vascularisation, the frequency of identical fingers on both hands may be more alike than those of different fingers. Also different fingers with comparable sizes may show a higher correspondence in frequency. This may lead to a higher PCC of neighbouring fingers. To test this hypothesis two hands were immersed in water simultaneously and 5 minutes apart. If the temperature profiles are becoming synchronised in the latter experiment a central component has to be present which overrides the autonomous rhythm of each finger.

In contrast to the previous investigation the water temperature was set to about 10°C. This caused less discomfort to the subjects and allowed a comparison in the response to two water temperatures.

In the first investigation the core temperatures were not determined, but it is very likely that general body cooling occurred during the investigation. The low water bath temperature (5°C) led to a heat loss of 35 W through the cooled hand during the last 30 minutes, which was probably not compensated for by the relatively low environmental temperature of 22°C. The resulting decrease in core temperature is known to decrease the CIVD response and to alter its frequency (Daanen et al., 1992). In this investigation the core temperature, measured in the rectum, was kept as constant as possible by a high environmental temperature and by adding radiation heat to the body when necessary.

2 MATERIALS AND METHODS

2.1 Subjects

Eight male subjects participated in the study. Their relevant anthropometric data is presented in Table I. The subjects were fully informed of the purpose of the study and of their right to withdraw from experimentation at any time and gave their consent.

The volume of both hands was determined by under water weighing. The palmar side of the hands were photocopied. The contours of the hand were marked and the surface area was determined by a computerised planimeter.

Table I Data of the subjects. Body surface area is calculated according to Dubois and Dubois (1916).

nr	age years	weight kg	length cm	body surface area m^2	palmar surface area cm^2		hand volume cm^3	
					left	right	left	right
1	24	67	183	1.87	181	178	480	476
2	36	67	172	1.79	164	167	475	455
3	25	83	182	2.04	150	150	460	470
4	25	74	180	1.93	157	159	520	520
5	21	75	198	2.08	195	185	560	545
6	39	63	171	1.74	152	150	415	420
7	27	75	184	1.97	166	173	478	495
8	20	70	186	1.93	176	177	450	440
Mean	27	72	182	1.92	167	167	480	478
SD	6	6	8	0.11	15	12	41	39

2.2 Procedure

The experiments were carried out in a climatic chamber. The ambient temperature (T_a) was 31°C with a relative humidity (RH) of 52%. Every subject came to the laboratory on two consecutive days on the same time of day. The subjects were sitting in front of the calorimeter in which both hands were immersed simultaneously (S) or 5 minutes in between (NS) (Table II).

Table II Immersion order.

subject	day of appearance	hand to be immersed first
1	1	both
	2	left
2	1	left
	2	both
3	1	both
	2	right
4	1	right
	2	both
5	1	both
	2	right
6	1	right
	2	both
7	1	both
	2	left
8	1	left
	2	both

The hands stayed in the calorimeter for at least 47 minutes after the immersion of the last hand. During the immersion period the rectal temperature was controlled by radiation on the back of the body. As soon as a decrease in temperature was seen, the amount of radiation was increased.

2.3 Temperature measurement

The temperature of the distal phalanx of the left and right index finger and the left middle finger was measured by a heat flux sensor with integrated thermocouple (Concept Engineering type FRM-200-T). The other 7 distal phalanx of the fingers were measured by copper-constantane thermocouples. The sensors were placed directly on the skin and fixed with 25 mm wide air-permeable tape (Leucoplast, Beiersdorf corporation).

The rectal temperature of the subjects was measured by a thermolinear probe (YSI 701) inserted 120 mm beyond the rectal sphincter.

2.4 Calorimetry

The heat transfer of the immersed hand(s) was determined and processed in the same way as by Daanen and Lotens (1992).

2.5 Data processing

The signals from the thermocouples, and thermopile of the calorimeter were sampled every 16 seconds. The calorimeter water flow was about 1.4 l/min and checked on the visual display throughout the experiments. The data were stored on a digital computer. The data were smoothed by a moving window (time constant of 2 min 24 s) (SYSTAT).

The initial 15 minutes of immersion were removed from the data set, because during these minutes the heat content of the hand is removed and the characteristic "hunting" response is only seen in the remaining part, leaving a period of about 32 minutes for subsequent analysis.

The skin temperature, heat transfer and water temperature were averaged over the immersion period after the 15th minute. Differences between subjects, S/NS and left/right hand were tested with an ANOVA. The interaction term subjects*left/right was included in the analysis.

The coefficient of variation (CV) was calculated for skin and water temperature and heat transfer. This parameter indicates the amount of fluctuation and can be seen as an estimate for the magnitude of the "hunting" response. Differences in CV between subjects, S/NS and left/right were tested with an ANOVA.

Pearson correlation coefficients (PCC) were calculated for the skin temperature registrations. The PCC is a sensitive estimator of the amount of correspondence. If one of the two compared temperature registrations shows a sudden increase while the other remains unchanged, a drastic reduction in the PCC results. However, the PCC may only be used if no time lag is present. It was shown in the previous investigation that the temperature registrations showed no systematic time lag. The mean PCC is calculated by averaging all PCC's of every possible combination of finger pairs. For ten fingers 9+8+7+6+5+4+3+2+1 = 45 PCC's are averaged. Because the PCC is not normally distributed due to a fixed maximum of 1, the comparisons between the PCC on several locations are made by the non-parametrical Kruskal-Wallis one way analysis of variance by ranks.

3 RESULTS

In Table III the resulting local skin temperatures are shown for every experimental situation, as well as the heat transfer and water temperature. There was no difference in finger temperature between the simultaneous and non-simultaneous immersion. Differences between the right and left hand were only found for the little finger. Subject differences were significant for all skin temperatures.

Table III Mean local skin temperature (°C), mean heat transfer (W) and mean water temperature (°C) during the last 32 minutes of immersion in cold water.

	simultaneous immersion		non-simultaneous immersion	
	left	right	left	right
thumb	13.8	13.5	13.7	13.0
index finger	13.8	13.6	14.0	12.9
middle finger	13.6	14.4	13.8	13.4
ring finger	13.5	13.3	13.5	12.4
little finger	13.4	12.5	13.3	12.1
calorimeter heat transfer	56.8		52.0	
water temperature	10.0		10.0	

In Table IV the coefficient of variation (CV) of local skin temperature and heat transfer is shown for every experiment. The CV for skin temperature showed significant inter subject differences for the thumb and index finger only. There was no difference between the simultaneous and non-simultaneous immersion and left/right. The CV of the calorimeter was 43% of the CV of the average finger skin temperatures. The water temperature was relatively constant. This means that the cooling capacity of the calorimeter was sufficient.

Table IV Coefficient of Variation (CV) of the local skin temperature (°C), heat transfer (W) and water temperature (°C) during the last 32 minutes of immersion in cold water. For the calculation of the CV of the finger temperatures the water temperature was subtracted in order to get a zero base.

	simultaneous immersion		non-simultaneous immersion	
	left	right	left	right
thumb	0.50	0.46	0.52	0.39
index finger	0.47	0.54	0.44	0.53
middle finger	0.54	0.49	0.53	0.51
ring finger	0.60	0.46	0.55	0.57
little finger	0.48	0.62	0.52	0.89
calorimeter	0.23		0.23	
water temperature	0.02		0.02	

In Table V the mean PCC for S and NS is shown for every subject. There was no difference in mean PCC of all the fingers between the simultaneous and non-simultaneous immersion (Kruskal-Wallis one way analysis of variance by ranks, n = 320, p = 0.22) (Table V).

Table V Mean PCC for all fingers (45 comparisons for every experiment).

subject	simultaneous	non-simultaneous
1	0.05	0.21
2	0.14	0.74
3	0.79	0.75
4	0.33	0.31
5	0.32	0.40
6	0.85	0.63
7	0.92	0.74
8	0.54	0.27
mean	0.49	0.51

The mean PCC is higher when a finger is compared to other fingers of the same hand (PCC = 0.63) than when comparing with other fingers of the opposite hand (PCC = 0.39) (Kruskal-Wallis one way analysis of variance by ranks, $p<0.001$). The mean PCC of corresponding fingers of the opposite hand is 0.45.

The PCC decreases when the distance between the compared fingers of one hand is increased. The differences are on the edge of significance (Kruskal-Wallis one way analysis of variance by ranks, $p=0.05$). In Fig. 1 the PCC of this investigation is compared to the results of the previous investigation (Daanen & Lotens, 1992). The mean PCC in the present investigation in one hand was 0.63, compared to 0.55 in the previous investigation. This was significantly different (Kruskal-Wallis one way analysis of variance by ranks, $p=0.04$).

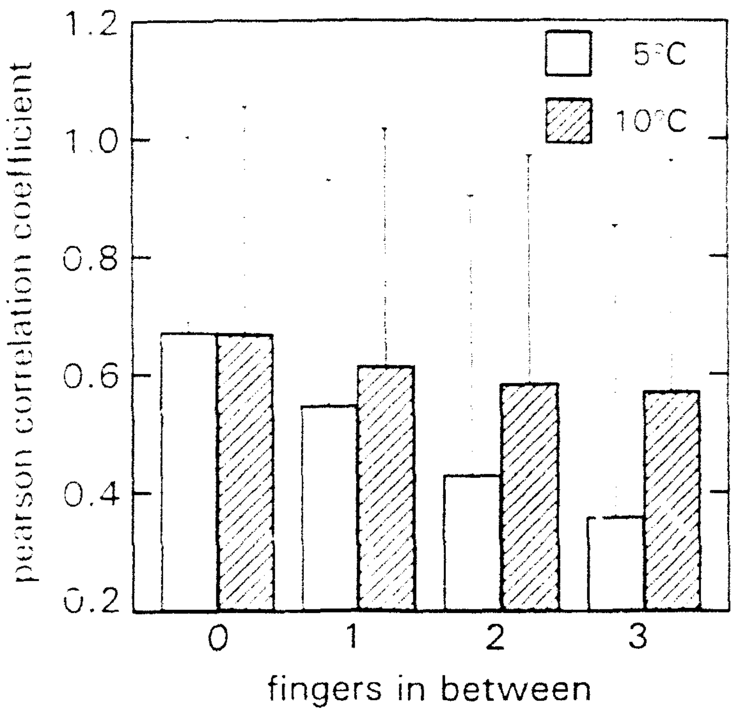

Fig. 1 Pearson Correlation Coefficients (PCC) for fingers with 0 (n=128), 1 (n=96), 2 (n=64) and 3 (n=32) fingers in between (hatched bars). The open bars are data from Daanen and Lotens (1992) with respectively 48, 36, 24 and 12 data points. The standard deviation is shown by thin solid vertical lines.

When the neighbouring fingers are split up in all possible combinations, the fingers with the highest correspondence in innervation (index-middle and ring-little finger) do not have higher PCC's (Table VI). The relation between the middle and ring finger is better than all the other combinations.

Table VI PCC's of neighbouring fingers (n=16).

	left hand	right hand
thumb-index	0.65	0.68
index-middle	0.57	0.57
middle-ring	0.82	0.88
ring-little	0.51	0.67

The rectal temperature remained relatively constant throughout the experiment. The average standard deviation was 0.045°C. In the second experiment of subject 5 and 6 the rectal sensor was damaged. About the success of the procedure to keep the core temperature constant for these subjects no more is known than that the same procedures was successful in the other experiments.

The amount of radiation energy applied to the subjects to control the rectal temperature varied significantly between subjects and was not different between S and NS (Table VII).

Table VII Total radiation energy (MJ) applied to the subjects during the immersion period for S and NS.

subject	simultaneous	non-simultaneous
1	0.9	0.0
2	0.4	0.1
3	3.0	3.8
4	1.5	3.2
5	0.7	0.0
6	0.0	0.1
7	2.1	0.5
8	0.1	0.2

The average heat transferred by the hands to the water was also constant. The heat transferred from the 15th to 25th minute was 54.8 W and from the 35th to 45th minute was 53.5 W (paired t-test, $p>0.05$).

4 DISCUSSION

In a previous report on CIVD (Daanen and Lotens, 1992) four theories concerning the mechanism of CIVD were discussed and compared with the results. The results of this investigation are not in perfect agreement with the previous ones. The differences and theoretical implications are discussed below.

Inter subject variability

In both investigations enormous differences between subjects existed in heat transfer, local skin temperature and the PCC's. Part of the explanation for the inter subject variability can be found in the fact that every subject has a specific threshold in core temperature above which heat transfer by the hands is started

(Daanen et al., 1991). This threshoid was determined in neither investigation. It may therefore well be that some subjects had a core temperature above their threshold, leading to central induced heat elimination in the hands. If we look in Table V, this may be the case for subjects 3, 6 and 7. Other subjects may have had core temperatures below their thresholds (this may for instance have been the case for subject 1). Their trigger to eliminate heat must be found in local mechanisms as CIVD. In future investigations it would be wise to determine the threshold and the core temperature during the experiments. The threshold is known to be altered when the average skin temperature and the hand skin temperature is changed. Therefore, the threshold determination has to be performed in the same setting as the CIVD experiments.

For subject 2 the mean PCC was much higher when the hands were immersed non-simultaneous. It would have been expected that the core temperature was higher for NS. This, however, was not the case: the rectal temperature was 0.17°C lower for NS than for S. Since ambient temperature and water bath temperature did not differ, the threshold should have been unaltered. Therefore, the explanation for this unexpected result is unknown.

Comparison with the previous investigation

The PCC of both investigations is almost the same for neighbouring fingers (Fig. 1). When the compared fingers are separated by other fingers, the PCC is reduced much more in the previous investigation. In the current investigation the PCC between thumb and little finger is 0.21 higher. This means that the fluctuations are more independent in the previous investigation, and that the current investigation involves a more central way of body heat elimination. The same conclusion can be drawn if the mean PCC of one hand in this investigation (0.63) is compared to the value of the previous investigation (0.55).

This investigation differs from the previous in number of immersed hands (two versus one), water bath temperature (10°C versus 5°C), ambient conditions (temperature 31°C versus 22°C, relative humidity 52% versus 22%) and core temperature (kept constant versus continuous decrease). It is very likely that the differences in ambient conditions and core temperature lead to a higher body heat content in this investigation. This causes a more central way of body heat elimination in the later investigation. Perhaps, the water temperature also plays a role. Probably, a lower water temperature leads to a relatively more local way of heat elimination, and a higher water temperature to a more central way.

The relatively higher influence of central body heat elimination in this investigation can also be seen when the CV of the calorimeter is compared to the CV of the local skin temperatures. In this investigation the CV of the calorimeter was 43% of the CV of the averaged local skin temperatures. In the previous investigation the CV of the calorimeter was only 31% of the CV of the local skin temperatures. This means that more synchronisation has to have occurred in this investigation.

In the previous investigation fingers sharing a major part of the same somatic nerves were shown to have a better correlation than neighbouring fingers with different innervation. In this investigation this was not the case. The middle finger and ring finger showed the best agreement. If the nervous involvement is only limited to local CIVD effects, these differences can be explained by the finding that local effects are less pronounced in this investigation due to the higher water temperature.

Simultaneous and non-simultaneous immersion

There were no differences in the PCC between simultaneous (S) and non-simultaneous (NS) immersion. It was expected that S would result in higher PCC's when a specific vasodilation rhythm for every finger was triggered at the moment of immersion. During the last 32 minutes of the immersion period, however, no differences were found for the average of all subjects. For many individual subjects the PCC varied a lot between the two experimental conditions (Table V).

The findings are in agreement with the data from Greenfield et al. (1951) who immersed the left and right index finger of three subjects in water of 0-6°C simultaneously and 5 and 10 minutes apart. When the immersion was performed simultaneously, the responses of the two sides became asynchronous after the heat of the tissue was eliminated. During the immersion period after non-simultaneous immersion the initial behaviour of each finger was independent of what was happening in the other. The results of only one subject were shown, but it was stated that two other subjects behaved similarly.

In Lewis (1930), however, the curves of the finger temperatures of both hands became concordant after about 45 minutes. Only one registration of non-simultaneous immersion was shown in his article, which made it impossible to determine if this should be considered as a normal response or an outlier.

In our experiment it may be assumed that the body was rather warm, due to the high environmental temperature and added radiation. This results in elimination of heat through the hands. This is probably such a powerful mechanism that the effects S or NS immersion were simply overruled. Therefore no differences in PCC between S and NS immersion are found. It may be expected that with a cold body local CIVD responses play a major role. This leads to a lower PCC for both simultaneous and non-simultaneous immersion but again no difference between S and NS immersion can be expected.

Constant core temperature

The attempt to keep the core temperature within small margins succeeded well. The average SD was only 0.045°C. As can be expected by the results of Daanen et al. (1991) this resulted in a rather constant heat transfer of the hands to the water.

5 CONCLUSIONS

Immersion of the hands in water of about 10°C lead to continuous fluctuations in finger skin temperature while the core temperature was kept constant. Compared to the previous investigation, in which the body heat content and water bath temperature was lower, the fluctuations were more alike. This was quantified by a high mean PCC of all fingers during immersion and the absence of differences in PCC between simultaneous and non-simultaneous immersion of two hands. The variability in PCC between subjects was rather high, and might be due to interindividual differences in central body temperature threshold above which heat elimination through the hands was started.

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

In an attempt to quantify the contribution of central and peripheral mechanisms to blood flow in the hands during immersion in cold water, eight male subjects immersed their hands simultaneously (S) and five minutes after each other (NS) in water of 10°C. Starting 15 minutes after immersion of the first hand, a period of 32 minutes was used for an analysis of the temperature fluctuations on all finger tips. The mean Pearson Correlation Coefficient (PCC) of all combinations of finger temperatures was taken as an indicator for the amount of central/local influence.
The PCC did not differ between S and NS. The mean PCC was 0.63, which implied a greater central influence than in a previous investigation (Daanen & Lotens, 1992), in which the body heat content and water temperature was lower (PCC = 0.55). The substantial central influence was also shown by the variation in heat transfer of the hands to the water, which was 43% of the average fluctuation in finger temperature and only 31% in the previous investigation. It is supposed that central heat elimination is predominant when the core temperature surpasses a subject specific threshold, and that its influence decreases when core temperature and water temperature decreases.

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