Cognitive and perceptual responses during passive heat stress in younger and older adults

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Schlader ZJ, Gagnon D, Adams A, Rivas E, Cullum CM, Crandall CG. Cognitive and perceptual responses during passive heat stress in younger and older adults. Am J Physiol Regul Integr Comp Physiol 308: R847–R854, 2015. First published March 18, 2015; doi:10.1152/ajpregu.00010.2015.—We tested the hypothesis that attention, memory, and executive function are impaired to a greater extent in passively heat-stressed older adults than in passively heat-stressed younger adults. In a randomized, crossover design, 15 older (age: 69 ± 5 yr) and 14 younger (age: 30 ± 4 yr) healthy subjects underwent passive heat stress and time control trials. Cognitive tests (outcomes: accuracy and reaction time) from the CANTAB battery evaluated attention [rapid visual processing (RVP), choice reaction time (CRT)], memory [spatial span (SSP), pattern recognition memory (PRM)], and executive function [one touch stockings of Cambridge (OTS)]. Testing was undertaken on two occasions during each trial, at baseline and after internal temperature had increased by 1.0 ± 0.2°C or after a time control period. For tests that measured attention, reaction time during RVP and CRT was slower (P ≤ 0.01) in the older group. During heat stress, RVP reaction time improved (P < 0.01) in both groups. Heat stress had no effect (P ≥ 0.09) on RVP or CRT accuracy in either group. For tests that measured memory, accuracy on SSP and PRM was lower (P < 0.01) in the older group, but there was no effect of heat stress (P ≥ 0.14). For tests that measured executive function, overall, accuracy on OTS was lower, and reaction time was slower in the older group (P ≤ 0.05). Reaction time generally improved during heat stress, but there was no effect of heat stress on accuracy in either group. These data indicate that moderate increases in body temperature during passive heat stress do not differentially compromise cognitive function in younger and older adults.

ADULTS OVER THE AGE OF ~65 YR are at an increased risk of illness, injury, hospitalization, and death during heat waves (23, 29, 33–36, 63, 64). Age-related impairments in physiological responses to heat stress undoubtedly contribute to this increased risk (32). Heat-stressed older adults have attenuated increases in skin blood flow (30, 31) and sweating (26, 27), as well as impaired cardiovascular adjustments (42, 43). However, both physiological and psychological states influence health and safety (52, 53). Thus, a variety of factors may mediate the deleterious outcomes observed in the older population during heat waves.

Healthy aging is associated with a general cognitive decline (49). Aspects of memory (4, 10, 12), attention (1, 12, 40), executive functioning (12, 58, 60), and processing speed (59) are typically [but not always (37, 48)] impaired with advancing age. This chronological cognitive decline may contribute to the risk of deleterious outcomes during heat waves in older adults by, for instance, leading to poor decision-making. Interestingly, perhaps because of the deleterious impact of heat stress on cerebral blood flow (46, 61) and/or disruptions in cerebral functional connectivity (66), many cognitive processes are impaired in heat-stressed younger adults [e.g., aspects of attention (19, 22, 65), memory (6, 19, 28, 41, 54), and executive function (16, 17, 67)], although this is not always observed (3, 50, 61). If heat stress-induced impairments in cognitive function are amplified with age, this might suggest that the contribution of cognitive factors to the risk of morbidity and mortality during heat waves would be exacerbated in older adults. However, the combined effect of heat stress and age on cognitive function remains unknown. Therefore, the purpose of this study was to test the hypothesis that indices of attention, memory, and executive function during passive heat stress will be reduced to a greater extent in healthy older, compared with younger, adults. The testing of this hypothesis will help define the role of psychological factors potentially contributing to the increased risk of morbidity and mortality during heat waves in the older population.

METHODS

Subjects

Fifteen older and fourteen younger, healthy subjects participated in this study. Each subject was fully informed of the experimental procedures and possible risks before giving informed written consent. The protocol and consent were approved by the Institutional Review Boards at the University of Texas Southwestern Medical Center at Dallas and Texas Health Presbyterian Hospital of Dallas. The subject characteristics are presented in Table 1. All subjects were nonsmokers, free of any cardiac, metabolic, neurological, or psychological diseases, and had normal, or corrected to normal, vision. Subjects taking drugs were excluded, with the exception of multivitamins and, in the older subjects only, prescription drugs for hypertension and hypercholesteremia. Subjects were mostly right-handed, were of normal, or above normal, cognitive abilities for their age (57), and most identified themselves as being physically active.

Subjects visited the laboratory on three occasions. Visit 1 was a familiarization trial that involved a health assessment, inclusive of vital signs (e.g., blood pressure and 12 lead ECG) and a complete health history, assessment of handedness (47), subjective levels of
Table 1. Subject characteristics

<table>
<thead>
<tr>
<th></th>
<th>Younger</th>
<th>Older</th>
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</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Age, yr</td>
<td>30 ± 4</td>
<td>69 ± 5*</td>
</tr>
<tr>
<td>Sex (male/female)</td>
<td>6/8</td>
<td>5/10</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.7 ± 0.2</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>74.5 ± 19.7</td>
<td>74.0 ± 14.6</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>25.3 ± 5.4</td>
<td>26.3 ± 4.1</td>
</tr>
<tr>
<td>Body surface area, m²</td>
<td>1.9 ± 0.3</td>
<td>1.8 ± 0.2</td>
</tr>
<tr>
<td>Handedness (right/left)</td>
<td>13/1</td>
<td>14/1</td>
</tr>
<tr>
<td>Montreal Cognitive Assessment score</td>
<td>29 ± 1</td>
<td>28 ± 1*</td>
</tr>
<tr>
<td>Corrected vision (yes/no)</td>
<td>4/10</td>
<td>10/5</td>
</tr>
<tr>
<td>Physical activity (high/moderate/low)</td>
<td>7/6/1</td>
<td>2/1/2</td>
</tr>
</tbody>
</table>

Values are expressed as means ± SD. *Significantly different from younger (P ≤ 0.016). All subjects were within the normal range for their age group [younger: ≥26; older: ≥23; (52, 53)]. *Stratified according to Craig et al. (9).
latency to correct choice (response time). Data are presented for overall performance, as well as across two levels of complexity: simple: those requiring two moves, and complex: those requiring six moves, similar to that done previously (16, 17). For this latter analysis, within a testing session, each measure was obtained by averaging the score obtained over four trials.

Visual analog scales (VAS) assessed subjective indices of mood, calmness, and alertness. Duration was ~2 min. Sixteen questions were answered using computerized VAS. These 16 questions were grouped according to Bond and Lader (2) (100-point scales) for measures of mood (0 = good, 100 = bad), calmness (0 = calm, 100 = excited), and alertness (0 = drowsy, 100 = alert).

Immediately prior to commencing and upon terminating each cognitive battery, thermal discomfort (4 point scale; 1 = comfortable, 4 = very uncomfortable) (14), thermal sensation (7 point scale; 1 = cold, 7 = hot) (14), and affect (11 point scale: 5 = feeling bad, +5 = feeling good) (24) were assessed on standardized scales. The duration was ~30 s. To reflect average levels of these perceptions during the cognitive battery, these data are presented as a mean of perception levels before and after each cognitive testing battery.

**Experimental Protocol (Visits 2 and 3)**

Following instrumentation, subjects rested quietly in a semirecum bent position, while 34°C water perfused the suit. Following at least 30 min of quiet rest, baseline cognitive testing was completed, after which the subjects underwent either whole body passive heat stress or a time control period, both of which were randomized (average duration − heat stress: 51 ± 5 min, time control: 52 ± 11 min, no differences between groups: P ≥ 0.518). Whole body passive heat stress was induced by perfusing 48°C water through the suit, sufficient to increase internal temperature ~1.0°C above baseline, while 34°C water was perfused through the suit during the time control period. Immediately following the heating/time control period, the subjects completed another cognitive assessment. During the heat stress trial, the temperature of the water perfusing the suit was not adjusted, thereby ensuring uncompensable heat stress and allowing internal temperature to continue rising throughout cognitive testing. This was by design, as the achievement of heat balance, independent of the magnitude of the increase in body temperature, can restore cognitive functioning (22). Whole body cooling was commenced immediately following completion of heat-stressed cognitive testing. The time control trial was utilized to ensure there was no effect of time, independent of heat stress, which might confound the interpretation of the findings during the heat stress trial. Subjects were not allowed to drink fluids at any time during either trial. Both experimental trials were conducted in a randomized manner. There were at least 48 h between the two trials, and both trials were conducted at the same time of day.

**Data and Statistical Analysis**

Heart rate and thermal data were sampled continuously at 50 Hz via a data acquisition system (Biopac MP150, Santa Barbara, CA). Subject characteristics between groups were compared using independent sample t-tests. All other data were analyzed using mixed-model ANOVA with one between- (age) and two within- (trial, time) subject factors. These data were assessed for approximation to a normal distribution and sphericity, and no corrections were necessary. When the ANOVA revealed a significant F test, post hoc pair-wise comparisons were made incorporating a Bonferroni adjustment. Data were analyzed using SPSS Statistics (version 22; IBM, Armonk, NY) with a priori statistical significance set at P ≤ 0.05. All data are reported as means ± SD.

**RESULTS**

**Thermal Changes**

Physiological data immediately prior to cognitive testing at baseline (i.e., before heat stress or time control period), during heat stress, and following the time control period are presented in Table 2. Baseline internal and mean skin temperatures, heart rate, and mean arterial pressure were not different between groups and trials, the exception being that in the younger group baseline internal temperature was slightly, but significantly, lower (by −0.1 ± 0.3°C, P = 0.031) in the heat stress trial than in the time control trial. As expected, internal (by +1.0 ± 0.2°C, P < 0.001) and mean skin (by +4.0 ± 0.7°C, P < 0.001) temperatures, as well as heart rate (by +33 ± 12 bpm, P < 0.001) increased equally (P = 0.504) between groups with heat stress, while mean arterial pressure was maintained in both groups (P ≥ 0.121). Mean skin temperature increased slightly (by +0.4 ± 0.6°C, P ≤ 0.021) during the time control period and was slightly lower (P = 0.006) in the older group at that time point. During the heat stress trial, body weight decreased (P < 0.001) in both groups, but the magnitude was greater (P = 0.003) in the younger group (Younger: −1.2 ± 1.0%, Older: −0.6 ± 0.8%). Body weight was unchanged in both groups during the time control trial (Younger: 0.0 ± 0.2%, Older: +0.1 ± 0.5%).

**Table 2. Physiological data immediately prior to commencing each cognitive test battery**

<table>
<thead>
<tr>
<th></th>
<th>Heat Stress Trial</th>
<th>Time Control Trial</th>
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<tbody>
<tr>
<td></td>
<td>Younger</td>
<td>Older</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal temperature, °C</td>
<td>36.9 ± 0.2*</td>
<td>37.0 ± 0.4</td>
</tr>
<tr>
<td>Mean skin temperature, °C</td>
<td>34.2 ± 0.4</td>
<td>33.9 ± 0.5</td>
</tr>
<tr>
<td>Internal-to-skin temperature gradient, °C</td>
<td>2.6 ± 0.4</td>
<td>3.1 ± 0.5*</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>67 ± 10</td>
<td>68 ± 9</td>
</tr>
<tr>
<td>Mean arterial pressure, mmHg</td>
<td>86 ± 12</td>
<td>93 ± 10</td>
</tr>
<tr>
<td><strong>Heat/Control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal temperature, °C</td>
<td>38.0 ± 0.2*</td>
<td>37.9 ± 0.3*</td>
</tr>
<tr>
<td>Mean skin temperature, °C</td>
<td>38.3 ± 0.6*</td>
<td>38.4 ± 0.6*</td>
</tr>
<tr>
<td>Internal-to-skin temperature gradient, °C</td>
<td>−0.3 ± 0.6*</td>
<td>−0.4 ± 0.7*</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>100 ± 12*</td>
<td>100 ± 16*</td>
</tr>
<tr>
<td>Mean arterial pressure, mmHg</td>
<td>80 ± 12</td>
<td>91 ± 11</td>
</tr>
</tbody>
</table>

Values are expressed as means ± SD. *Significantly different from younger within trial at same time point (P ≤ 0.022). †Significantly different from baseline within trial and age group (P ≤ 0.021). ×Significantly different from time control trial at same time point (P ≤ 0.033).
Cognitive Function and Perceptual Indices

Performance on the computerized tests evaluating aspects of attention (RVP, CRT) is presented in Fig. 2. As expected, reaction time during RVP and CRT was slower ($P ≤ 0.003$) in the older group. During heat stress, reaction time improved from baseline ($P ≤ 0.001$) in both groups during RVP, and heat stress had no effect ($P ≥ 0.094$) on RVP or CRT accuracy in either group. Performance on tests evaluating aspects of memory (PRM, SSP) is presented in Fig. 3. Overall accuracy on SSP and PRM was lower ($P < 0.001$) in the older group compared with the younger group, but there was no effect of heat stress ($P ≥ 0.142$). Performance on OTS, evaluating aspects of executive function, is presented in Table 3. Overall, accuracy was lower, and reaction time was slower in the older group compared with the younger group ($P ≤ 0.050$). Reaction time generally improved during heat stress, but there was no effect of heat stress on aspects of accuracy ($P ≥ 0.218$). OTS performance on simple (those requiring two moves) and complex (those requiring six moves) tasks were identical to that observed for the overall performance (those requiring 1–6 moves, data not shown).

Perceptual indices are presented in Fig. 4. Heat stress increased ($P ≤ 0.022$) thermal discomfort, sensations of warmth, reduced affect, worsened mood, and increased excitement, and there were no differences between groups ($P ≥ 0.148$). Heat stress was associated with increased reporting of alertness, but only in the older group ($P = 0.028$).

DISCUSSION

This study tested the hypothesis that passive heat stress, sufficient to increase internal temperature 1.0–1.6°C (Table 2,
Elevations in Body Temperature and Cognitive Function

Various aspects of attention (19, 22, 65), memory (6, 19, 28, 41, 54), and executive function (16, 17, 67) are reduced in heat-stressed younger adults. Therefore, our findings that passive heat stress did not affect the measured indices of cognitive function are unexpected (Figs. 2 and 3, Table 3). This finding is even more surprising given that performance on these exact tests was reduced in heat-stressed younger adults utilizing a similar sample size (range: 8–18 subjects), e.g., OTS (16, 17), RVP (19), PRM (19, 54), and SSP (19, 54). Thus, we are confident that our findings are not due to a lack of sensitivity, as has been speculated as a confounding factor in other similar studies (e.g., 3, 61).

It is noteworthy that in the aforementioned studies, subjects were exposed to extremely hot environments (range: 44–50°C, Fig. 3). Performance on tests evaluating aspects of memory in younger (n = 14) and older (n = 15) subjects during heat stress and time control trials at baseline and during heat stress (i.e., heat) and following a time control period (i.e., control). Top: spatial span test (SSP). Bottom: pattern recognition memory test (PRM). Data are presented as means ± SD. *Significantly different from younger within trial(s) at same time point(s) (P < 0.001).

Table 3. One touch stockings of Cambridge performance

<table>
<thead>
<tr>
<th></th>
<th>Heat Stress Trial</th>
<th>Time Control Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Younger</td>
<td>Older</td>
</tr>
<tr>
<td></td>
<td>Overall (1–6 moves)</td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems solved on 1st choice</td>
<td>21.1 ± 2.2</td>
<td>18.5 ± 3.3*</td>
</tr>
<tr>
<td>Choices to correct answer</td>
<td>1.1 ± 0.1</td>
<td>1.3 ± 0.2*</td>
</tr>
<tr>
<td>Latency to 1st choice, s</td>
<td>14.4 ± 4.6</td>
<td>24.2 ± 10.1*</td>
</tr>
<tr>
<td>Latency to correct, s</td>
<td>17.2 ± 6.6</td>
<td>31.3 ± 12.5*</td>
</tr>
<tr>
<td>Heat/control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems solved on 1st choice</td>
<td>20.9 ± 2.5</td>
<td>17.9 ± 3.2*</td>
</tr>
<tr>
<td>Choices to correct answer</td>
<td>1.2 ± 0.2</td>
<td>1.4 ± 0.3*×</td>
</tr>
<tr>
<td>Latency to 1st choice, s</td>
<td>10.4 ± 3.2†</td>
<td>18.0 ± 7.6××</td>
</tr>
<tr>
<td>Latency to correct, s</td>
<td>12.1 ± 3.6†</td>
<td>24.0 ± 11.3×†</td>
</tr>
</tbody>
</table>

Values are expressed as means ± SD. *Significantly different from younger within trial at the same time point (P ≤ 0.050). †Significantly different from baseline within trial and age group (P ≤ 0.049). ×Significantly different from time control trial at same time point (P ≤ 0.049).
speculated that the neuronal demand of the cognitive tasks in related differences persisted (Figs. 2 and 3, Table 3), it can be aspects of cognitive function in either group, but that age-related differences in aspects of perception and cognitive function. This passive heat stress method resulted in increases in thermal discomfort, sensations of warmth, reductions in mood and affect (Fig. 4), and general enhancements in processing speed (reaction time) (Fig. 2, Table 3). However, it did not affect any measure of cognitive function accuracy (Figs. 2 and 3, Table 3). The rationale underlying the current observations remains unknown, especially in light of recent findings, indicating that negative affect and thermal discomfort associated with heat stress impairs aspects of executive function (specifically, OTS) increased dynamic increases in skin temperature (17), whereas mean skin temperature remained stable during the cognitive tests in the current study. As such, it may be that the potential deleterious cognitive impact of negative affect and discomfort is constrained to instances in which only skin temperature is increasing (17), as opposed to when skin temperature is stable and only internal temperature is rising (Fig. 1).

Impact of Age

Healthy aging is generally associated with reductions in aspects of memory (e.g., 17), attention (4, 10, 12), executive functioning (1, 12, 40), and processing speed (12, 58, 60). The current findings generally support this, as accuracy on the measured indices of memory (Fig. 3) and executive functioning (Table 3) were lower, and processing speed was slower (Fig. 2, Table 3) in the older group. Such findings suggest the current tests, in combination with the moderate sample size, were sensitive to cognitive differences typically associated with aging. Importantly, however, a novel aspect of this study is that age-related differences were not exacerbated with moderate increases in body temperature in the older group (Figs. 2 and 3, Table 3). Thus, the measured aspects of cognitive function were unaffected by passive heat stress in both younger and older subjects.

Aging heightens the cerebral neuronal demands of a cognitive task, and when the demand is greater than the neuronal resources available, task accuracy and reaction time are diminished (59). Interestingly, the deleterious effects of heat stress on prior assessments of cognitive function appear to be dictated by a similar mechanism, such that heat stress increases the neuronal demand of a cognitive task (39, 55) and disrupts cerebral functional connectivity (18, 25, 38). Given that passive heat stress did not affect accuracy on any of the measured aspects of cognitive function in either group, but that age-related differences persisted (Figs. 2 and 3, Table 3), it can be speculated that the neuronal demand of the cognitive tasks in the current paradigm was unaffected by the passive heat stress method utilized in this study.

The ability to perceive warm and cool temperatures is generally reduced with age (66). Furthermore, a given reduction in internal temperature elicits less thermal discomfort in older, compared with younger, adults (21). The current findings indicate that moderate passive heat stress is perceived as similarly warm and uncomfortable in both younger and older subjects (Fig. 4). Such findings were particularly surprising given that discomfort dictates the decision to initiate adaptive behavioral responses during thermal stress (e.g., change the temperature in a room, etc.) (13) and that the decision to initiate such behavior is incumbent upon greater changes in body temperature in older adults (62). Thus, it may be that older adults are less sensitive to reductions in body temperature, but sensitivity to increases in body temperature is well maintained. However, direct evidence for such an arrangement is required.

Other Considerations

Because of sweat production, dehydration typically accompanies heat stress and subsequent increases in body temperature (8, 45, 68). Notably, mild dehydration (i.e., ≤2% body weight loss) is usually associated with impairments in various aspects of cognitive function, including aspects of attention (5), memory (7, 15, 20), and executive function (6, 7, 20). Although this study was not designed to evaluate hydration status as a modulator of cognitive function, it is notable that body weight decreased on average less than 2% in the younger and older subjects. Given that the measured aspects of cognitive function were unchanged during heat stress, which induced mild dehydration (Figs. 2 and 3, Table 3), such findings suggest that mild dehydration has little impact on attention, memory, and executive function during passive heat stress as measured herein. Interestingly, given that the magnitude of dehydration was less in the older subjects (−1.2% vs. −0.6), it remains unknown whether dehydration during passive heat stress equally impacts cognitive function in both younger and older adults.

Perspectives and Significance

Older adults are at an increased risk of morbidity and mortality during heat waves (15, 20). Impaired physiological responses to heat stress likely contribute to this increased risk (23, 29, 33–36, 63, 64). However, given that both physiological and psychological responses dictate health and safety (32), psychological factors may also modulate the increased risk of deleterious outcomes during heat waves in the older population. The current study indicates that changes in aspects of cognitive function are not exacerbated with advancing age during heat stress. That said, during passive heat stress, classic age-related differences in aspects of cognitive function persisted. Such findings do not discount a potential cognitive contribution to the increased risk of morbidity and mortality during heat waves in the older population, but rather suggest that the cognitive contribution is not exacerbated by moderate increases in body temperature. It should also be noted that while the computerized tests used in the present study have been shown to be sensitive to abnormal cognitive function and did show the expected age-related differences, it remains to be seen whether other neuropsychological measures might prove sensitive to the hypothesized effects of heat stress. Clearly,
further studies are required to understand the multifaceted nature of this risk. Such information is important, as understanding such risk will allow for the development of interventions and countermeasures aimed at protecting the older population during heat waves.

Conclusions

The present study indicates that moderate increases in body temperature and a narrowing of the internal-to-skin temperature gradient during passive heat stress do not compromise the assessed aspects of attention, memory, or executive function in younger or older adults. That said, the expected age-related differences in cognitive performance were apparent independent of changes in body temperature. The present findings also indicate that both older and younger adults generally perceive increases in body temperature similarly.

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GRANTS

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS


REFERENCES