The Effect of Cooling the Head to Reduce Brain Temperature on Stress

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Abstract

Stress is associated with a vast array of negative outcomes for both physical and mental health. Based on evidence that stress influences temperature, and that psychology and physiology influence each other, we investigated the novel possibility that reducing brain temperature reduces stress in a sample of 91 university students. We used head fanning to reduce brain temperature and measured this change with an infrared ear thermometer. Participants were randomly assigned so that the fans faced toward half of the participants (cooling condition) and faced away from the other half (non-cooling control condition). Differences in stress between conditions during the Vandenberg and Kuse (1978) Mental Rotations Test were then examined to test the hypotheses that (a) cooling would buffer stress and (b) that this would be mediated by changes in brain temperature, as indicated by ear temperature. Participants in the cooling condition were less stressed ($p = .02$) and also performed better ($p = .03$) during the task but neither of these findings were mediated by ear temperature. Thus, some uncontrolled variable(s), and not changes in temperature, may have been responsible for the effect of cooling on stress. Alternatively, error in measuring brain temperature may have obscured the hypothesised causal relationship between temperature and stress. More research is needed to confirm whether cooling the head is a simple way to manage stress.

The Effect of Cooling the Head to Reduce Brain Temperature on Stress

Overview

Despite being a difficult concept to define (Cooper & Dewe, 2008), stress is associated with a vast array of negative outcomes for both physical and mental health, including the two leading causes of death in the Western world: cancer and cardiovascular disease (Barlow & Durand, 2012; World Health Organisation, 2011). The related costs of stress are consequently reported in the millions of dollars each year, and methods to reduce stress are as valuable as they are desirable (Cooper & Dewe, 2008). In this context, the present study investigated the novel possibility that reducing temperature reduces stress**.** This was based on evidence that stress influences temperature, and that psychology and physiology influence each other, such that temperature might also influence stress. We first review the literature relevant to our proposition and then report the results of an experiment to test it.

Stress and Increased Temperature

Body temperature

Stress increases body temperature via arousal of the sympathetic branch of the autonomic nervous system that prepares the body for fight-or-flight (Taylor, 2012; Vinkers et al., 2008). This increase in temperature has been studied extensively in animals. For example, experiments with rodents have produced temperature increases of as much as 2°C in response to numerous animal models of psychological stress, including social defeat stress, handling stress, open-field stress, cage-change stress, cage-exchange stress, and anticipatory anxiety stress (Bouwknecht, Olivier, & Paylor, 2007; Lkhagvasuren, Nakamura, Oka, Sudo, & Nakamura, 2011; Oka, Oka, & Hori, 2001). This phenomenon is so robust that it is used to test the anxiolytic properties of drugs in a procedure called the stress-induced hyperthermia paradigm (Van der Hayden, Zethof, & Olivier, 1997). The first step in this procedure is to measure rectal temperature. This provides a baseline temperature measurement and also operates as a stressor capable of increasing body temperature like the psychological stress models above. Because stress-induced hyperthermia peaks within 10-15 minutes, another rectal temperature measurement is then taken after 10 minutes. The increase in temperature between these two measurements represents the magnitude of the stress response and allows researchers to test the anxiolytic properties of various drugs; if the response is diminished, a drug has an anxiolytic effect (Vinkers et al., 2008). This effect is not limited to rodents either. Increases in body temperature in response to stress have been reported in a diverse range of other species, including baboons, silver foxes, pigs, ground squirrels, rabbits, and even reptiles (where stress promotes heat-seeking behaviour, the only way that they can raise body temperature; Bouwknecht et al., 2007; Cabanac & Gosselin, 1993).

Although the relationship between stress and body temperature has received less attention in humans, the available evidence suggests that we respond to stress in a similar way. This has mainly been studied in the context of students sitting exams. The first study of this kind was conducted by Marazziti, Di Muro, and Castrogiovanni (1992), who found that the mean axillary (armpit) temperature of psychiatry students was 0.60°C higher before a yearly exam than during a calm situation 2-3 weeks later. This finding was later replicated by Briese (1995), who found a similar increase in mean oral temperature of 0.18°C in medical students before a stressful exam compared with before a non-stressful lab demonstration three days later. Thus, body temperature in humans also appears to be increased in response to psychological stress. Additional evidence of this comes from case reports of people with elevated body temperatures in stressful situations such as during arguments or visiting a strict mother (Oka et al., 2001). This is generally referred to as "psychogenic fever" and has been reported to increase temperature to as much as 39°C (human body temperature is normally regulated at approximately 37°C) and can remain high for weeks or even years (Oka et al., 2001).

Brain temperature

In contrast to body temperature, stress-related changes in brain temperature have not been emphasised in previous research. A major reason for this is that measuring brain temperature directly requires invasive procedures that are inappropriate in healthy human populations. Despite this, there is reason to believe that stress also increases the temperature of the brain. A major determinant of brain temperature is the temperature of the arterial blood that goes to the brain (Harris & Andrews, 2005). Because stress increases body temperature, this mechanism will bring warm blood from the body to the brain, increasing brain temperature upon arrival during stress. In addition, the cognitive load of stress may further increase local temperatures within the brain due to heightened glucose metabolism, as seen with cognitively demanding tasks (Gallup & Gallup, 2008). Consistent with this, Wolf (1990, as cited in Zajonc, Murphy, & McIntosh, 1993) found that people who were stressed because they thought they had done poorly on an IQ test had increased forehead temperatures, which are an estimate of brain temperature (Kirk, Rainey, Vail, & Childs, 2009). Finally, recent research on yawning as a compensatory brain cooling mechanism has shown that people yawn more when brain temperature is increased and yawn less when brain temperature is reduced (Gallup & Gallup, 2007, 2008; Shoup-Knox, Gallup, Gallup, & McNay, 2010). Because stressful situations are conducive to yawning in humans, nonhuman primates, and rats (Gallup & Gallup, 2008), this further suggests that brain temperature, specifically, increases during stress. Sympathetic nervous system activation in response to stress therefore increases body temperature in animals and humans, and is believed to increase brain temperature as well.

The Interrelationship Between Psychology and Physiology

As we have seen, stress influences temperature. Conversely, it is possible that temperature influences stress because psychology and physiology influence each other. Indeed, modern health psychology views stress and other health-related issues as the product of an interrelationship between biological, psychological, and social factors. This is known as the biopsychosocial model (Engel, 1977; Schwartz, 1982). Central to this model is the idea that change in any of these factors will bring about change in the other factors as well (Taylor, 2012). In other words, the causal relationships between these variables go both ways. For the purposes of the present study, this means that psychological factors do not just influence physiology, as was once believed to be the case (e.g., Alexander, 1950; Dunbar, 1943), but physiological factors also influence psychology.

A well-known example of this two-way relationship between psychology and physiology is the question: Do we smile because we are happy or are we happy because we smile? Although counterintuitive, this latter proposition, based on the theorizing of Charles Darwin and William James (McIntosh, 1996), has slowly gained support. An early experimental demonstration of this facial feedback effect was conducted by Strack, Martin, and Stepper (1988), who found that participants who held a pen in their mouth with their teeth (to imitate smiling) rated cartoons as more amusing than participants who instead held the pen with their lips (more like a frown). Similarly, Zajonc, Murphy, and Inglehart (1989) had participants produce vowel sounds that mimicked facial expressions associated with various emotions and then rate their subjective mood. The phonemes *e* and *ah* were associated with the most positive mood and the phoneme *ü* was associated with the worst mood. These and other related studies (e.g., Kleinke, Peterson, & Rutledge, 1998; McIntosh, Zajonc, Vig, & Emerick, 1997) suggest that facial expressions influence the subjective experience of emotion.

The facial feedback effect is not just restricted to smiling. Recent research has replicated it in people who have had botulinum toxin A treatment (commonly known as Botox) for frown lines, which temporarily paralyses the facial muscles involved in frowning (reviewed in Lewis, 2012). A side effect of this treatment is impaired facial expression of negative emotions. Consistent with the facial feedback effect, Lewis and Bowler (2009) found that these patients were significantly less depressed and less anxious than patients who received other forms of cosmetic treatment, and this was not due to differences in self-rated attractiveness. Other emotions that are influenced by facial feedback effects include anger, fear, sadness, surprise, and disgust (Flack, 2006; Lewis, 2012). This research does not argue that facial expression is the sole determinant of emotion (McIntosh et al., 1997). It is clearly not. Instead, it supports the idea that psychology and physiology influence each other.

Two-way relationships between psychology and physiology are also seen in the context of stress. A good example of this is biofeedback, an intervention used to manage stress by reducing the physiological symptoms associated with it. This is done by making functions of the autonomic nervous system that are involved in the stress response, such as heart rate and blood pressure, either visible or audible using physiological monitoring equipment (e.g., ECG for heart rate). Using this feedback, people can learn to control these functions. This procedure has reduced stress and anxiety in students (Henriques, Keffer, Abrahamson, & Horst, 2011), children (Wenck, Leu, & D'Amato, 1996), anxiety disorder patients (Reiner, 2008), and basketball players (Paul & Garg, 2012). Although there are a number of possible mechanisms involved (McKee, 2008), this research suggests that people can reduce stress and anxiety by reducing the physiological symptoms that accompany it. Like facial feedback effects, this supports the idea that psychology and physiology influence each other.

Lessons from the Vascular Theory of Emotional Efference

Because stress influences temperature, and psychology and physiology influence each other, temperature may also influence stress. Further support for this proposition is derived from the vascular theory of emotional efference developed by Zajonc and colleagues (reviewed in Zajonc et al., 1993) to explain the facial feedback effect outlined above. The vascular theory of emotional efference argues that various facial expressions alter the amount of air that can be inhaled through the nose in normal breathing, that this influences cooling of arterial blood flowing to the brain via the cavernous sinus, and that the changes in brain temperature produced influence the subjective experience of emotion. To explain the relationship between brain temperature and emotion proposed by this theory, Zajonc and colleagues pointed out that, "since biochemical processes are temperature-sensitive, emotion-related neurotransmitters are sensitive as well" (1993, p. 212).

These ideas are also relevant to stress. In particular, release of the stress hormone cortisol has been shown to be extremely sensitive to changes in temperature, such that the amount of circulating cortisol increases dramatically as temperature rises (Cameron et al., 2010). Temperature may therefore influence the subjective experience of stress through its effects on the endocrine system (which includes the hypothalamic-pituitary-adrenal axis that stimulates cortisol production during stress; Barlow & Durand, 2012). More specifically, because cortisol increases as temperature rises, increased temperature may increase stress and, conversely, reduced temperature may reduce stress. This latter proposition is especially attractive because it could provide novel approaches to stress management and is supported by additional converging lines of evidence from research on sleep, exercise, and inflammation.

Reduced Temperature and Stress

First, like all mammals, humans normally sleep when their body temperature is at its coolest (due to natural fluctuations in the circadian rhythm of core body temperature; Glotzbach & Heller, 2000). This is not a coincidence. Additional research has shown that this reduction in core body temperature (via increased heat loss from the hands and feet) is actually crucial for the onset of sleepiness and sleep, and that this mechanism is believed to be partly involved in the sleep-promoting effects of drugs like benzodiazepines and alcohol (Kräuchi, Cajochen, Pache, Flammer, & Wirz-Justice, 2006). This suggests that cooler body temperatures are associated with relaxed psychological states and, further, that cooling may elicit these relaxed states.

Second, regular aerobic exercise reduces temperature and stress. A previous study conducted by Baum, Bruck, & Schwennicke (1976) found that long-distance runners had lower resting body temperatures than physically untrained controls (but see also Soare, Cangemi, Omodei, Holloszy, & Fontana, 2011). In addition to reducing temperature, exercise has been shown to reduce ratings of perceived stress and the incidence of stress-related health issues such as poor sleep quality, high blood pressure, and illness susceptibility (Brown & Siegel, 1988; Castro, Wilcox, O'Sullivan, Baumann, & King, 2002; King, Baumann, O'Sullivan, Wilcox, & Castro, 2002). Although there are a number of possible mechanisms involved in this effect (Taylor, 2012), the co-occurrence of lower temperatures and lower stress levels in physically fit individuals also suggests that cooler body temperatures may be associated with reduced stress.

Finally, temperature is known to influence inflammation, which is related to stress. Previous research has shown that psychological stress increases the production of pro-inflammatory cytokines that cause inflammation (Maes et al., 1998), and that this is mediated by the release of glucocorticoids (stress hormones like cortisol; Dobbs, Feng, Beck, & Sheridan, 1996). These cytokines further stimulate glucocorticoid release in a positive feedback loop, which has been hypothesised to exacerbate the stress response (Cohen, Doyle, & Skoner, 1999). Consistent with this, chronic inflammation is argued to be a contributing factor in the development of stress-related disorders such as anxiety and depression (Rook & Lowry, 2008). Importantly, inflammation is reduced when body and brain temperature is cooler (Whalen et al., 1997), suggesting that cooler temperatures may reduce stress by reducing inflammation.

Towards an Experiment

Based on the evidence outlined above, the aim in the present study was to test the novel possibility that reduced temperature reduces stress. The reviewed research suggests that both body and brain temperature may influence stress. However, because the subjective experience of stress is a psychological phenomenon and because the brain is the psychological organ, we chose to focus on brain temperature in this preliminary study. We therefore needed to be able to manipulate and measure brain temperature in a sample of healthy volunteers. Although neither is straightforward, recent interest in the neuroprotective qualities of a cool brain following brain injury (therapeutic hypothermia; Mayer & Sessler, 2005) offers solutions to both of these issues.

Manipulating brain temperature

In a review of the medical literature, Harris and Andrews (2005) identified a number of ways to reduce brain temperature and divided these into those that are invasive (and only appropriate in the medical context) and those that are not. Of the non-invasive options, head fanning is a promising method that utilises natural cooling mechanisms of heat loss through the skull (Harris & Andrews, 2005; for anatomical considerations, see Zenker and Kubik, 1996). Subsequently, Harris and colleagues (Harris, Andrews, & Murray, 2007) have shown that 30 minutes of head fanning of ambient air with electric fans produced a mean brain temperature reduction of 0.26°C in brain-injured patients. This group then replicated this effect in healthy volunteers using a custom-built device that delivered high flow rates of cold air to the head. Within 30 minutes, this device reduced overall brain temperature, measured using magnetic resonance spectroscopy, by an average of 0.45°C (Harris, Andrews, Marshall, Robinson, & Murray, 2008). For the purposes of our study, head fanning is therefore a simple but effective method of reducing brain temperature. Because obtaining a head cooling device like the one used by Harris et al. (2008) was beyond the means of the present study, we instead adapted the procedure of Harris et al. (2007) and used bilateral head fanning of ambient air to reduce brain temperature.

Measuring brain temperature

Measuring brain temperature in healthy volunteers is complex because the invasive methods required to measure temperature directly are inappropriate (see Hlatky & Robertson, 2005). Instead, the temperature of the brain must be estimated using an extracranial site of measurement. Whereas many traditional core body temperature measurements are poor indicators of brain temperature, especially during rapid temperature change (Hlatky & Robertson, 2005), Mariak, White, Lyson, and Lewko (2003) demonstrated that the temperature of the tympanic membrane in the ear closely reflects changes in brain temperature (of particular relevance to the present study, these temperature changes were in response to head fanning). Accordingly, tympanic membrane temperature is the leading non-invasive method of brain temperature estimation used in neurosurgical practice in the United Kingdom

(Johnston, King, Protheroe, & Childs, 2006). Tympanic membrane temperature can be assessed using an infrared ear thermometer that measures heat radiating out from the tympanum. While this method is not perfect (e.g., McCarthy & Heusch, 2006), it is a simple and relatively inexpensive option that should nevertheless be sensitive to changes in brain temperature. We therefore chose to use tympanic temperature measured using an infrared ear thermometer as a non-invasive indicator of brain temperature in the present study.

Hypotheses

The aim of this study was to experimentally test the novel possibility that cooling the head to reduce brain temperature could reduce stress. To do this, we attempted to reduce brain temperature using head fanning and measured this change using an infrared ear thermometer. We then examined differences in stress responses during a stressful cognitive task for a group of participants who received head fanning and a control group who did not. This task was used to ensure that the participants were sufficiently stressed to allow us to detect a reduction in stress caused by cooling (i.e., the stressful task helped avoid the possibility of a floor effect in stress experienced by the participants). We tested two hypotheses. First, we hypothesised that head fanning would buffer stress responses during the task (Hypothesis 1). Second, we hypothesised that this would be mediated by a reduction in brain temperature, as indicated by ear temperature (Hypothesis 2). If reducing the temperature of the brain does reduce stress, it would enhance our understanding of stress and the interrelationships between physiology and psychology generally, as well as offer novel approaches to the management of stress.

Method

Participants

We recruited 100 students from the University of Canterbury using advertisements posted around the university campus, the 100-Level Psychology Department Participation Pool and recruitment emails sent to undergraduate students in the Psychology Department. Participants received a $10 shopping voucher or course credit (in the case of those drawn from the Participation Pool) for taking part. Of these 100 participants, nine were excluded from analysis: two knew the experimenter well (which may have compromised the stressfulness of the task), one had language difficulties, and data for one was unusable due to equipment failure. The remaining five participants expressed extreme suspicion about either the temperature manipulation or stress manipulation during debriefing. Subsequently, data from 91 participants (26 males and 65 females) aged between 18 and 45 years (*M* = 22.89 years, *SD* = 5.13) was used for analysis.

Procedure and Apparatus

The participants were tested individually in a small laboratory room. Upon arrival, participants were greeted and asked to take a seat before being provided with an overview of the study that explained the cover story. Specifically, participants were told that we were investigating how white noise affects people's psychology and physiology and, in particular, how it affects people's performance on intelligence-related tasks. To that end, the participants were told that they would be exposed to some white noise and then given a short test of spatial intelligence, and that we would measure a number of related psychological and physiological factors throughout the experiment (namely, stress and temperature). The 'white noise' was the sound of two fans placed in front of the participants (which were actually used to reduce brain temperature by fanning the head). In this way, participants were blind to condition and to the true purpose of the study. Participants were then given an information sheet and a consent form to sign. Copies of these are provided in Appendix A.

Commencing the experiment, participants were given a questionnaire that assessed trait and state stress, mood, speed of thoughts, and enjoyment of spatial intelligence problems. After completing the questionnaire, a baseline temperature measurement was taken in each ear. The order of measurement was counterbalanced so that half of the participants had their temperature taken first in the left and then right ear throughout the study, and vice versa for the other half of the participants. All measurements were made by inserting a Braun ThermoScan Pro 4000® infrared ear thermometer (Braun, USA) into the ear canal of the participant. A new disposable probe cover was used for each measurement to prevent cross-contamination and to ensure the most accurate recording, as per the manufacturer's recommendations. The thermometer's temperature reading was sensitive to 0.1°C (e.g., 36.9°C). The same experimenter performed all of the temperature measurements.

Next, the participants underwent 12 minutes of fanning, which they were told was to expose them to white noise but which was really used to experimentally cool the brain. Two electric pedestal fans (Evantair, NZ) were positioned 90 centimetres in front and to either side of the participants' chair at a height of 110 centimetres, tilted up towards the head and away from the torso to maximise head cooling. The fans ran on the highest speed and without oscillation with a total airspeed of approximately 7.2 m s^{-1} (3.6 m s^{-1} each), comparable to the 8 m s^{-1} used by Harris et al. (2007). Participants were randomly assigned to conditions so that the fans faced half of the participants (cooling condition; $n = 43$) but were turned around to face away from the other half of the participants (non-cooling control condition; $n = 48$). In this way, the participants' experience between conditions was essentially identical except for the presence or lack of airflow (head fanning). During fanning, participants in the cooling condition also had their arms covered with a towel to minimise body cooling. In both conditions, the participants were asked to remain seated between the fans with their eyes open and to move as little as possible. The experimenter waited quietly in an adjacent room while the fans were on. Room temperature and relative humidity were assessed prior to fanning using a combined electronic thermometer/hygrometer (iROX, Switzerland) accurate to 0.1°C and 1% humidity. Mean room temperature was 21.50°C (*SD* = 1.04°C; 18.1–23.6°C) and relative humidity was 37.90% (*SD* = 2.81%; 34–47%).

After the 12 minutes, the fans were turned off and participants were given a second questionnaire, which assessed stress, mood and speed of thoughts. Upon completing the questionnaire, ear temperature was measured as before.

Next, participants performed the Vandenberg and Kuse (1978) Mental Rotations Test (MRT), updated by Peters et al. (1995) and slightly modified for presentation on a computer screen placed in front of participants. The participants were told that the task would test whether white noise could help people to perform better on problems that require spatial intelligence. However, we were really interested in the effect of cooling on the stress elicited by this task. The MRT is a well-established test of spatial ability (Peters & Battista, 2008). The test was comprised of 24 items, each consisting of a target figure and four comparison figures. Participants were required to correctly identify which two of these four comparison figures were rotated versions of the target figure. See Figure 1 for an example MRT item. The items were presented one at a time in a fixed order of increasing difficulty. Upon completion of an item, the next problem was presented (controlled by the experimenter). To increase the stress elicited by the test, the participants only had three minutes to work on the MRT (displayed on a countdown timer beside the computer screen). In addition, they were told that to score well they should work as quickly and as accurately as possible and that their performance would be used to evaluate their spatial intelligence. To add an element of social stress, the participants also communicated their answers verbally to the experimenter (comparison figures were labelled a, b, c and d) who recorded them. The participants were provided with one practice problem before the test.

After the test, participants were given two final questionnaires. The first assessed stress, mood and speed of thoughts during the task and the second assessed basic demographics and the participants' experience during the experiment. Upon completion of these two questionnaires, the experimenter probed for suspicion before debriefing and thanking the participant.

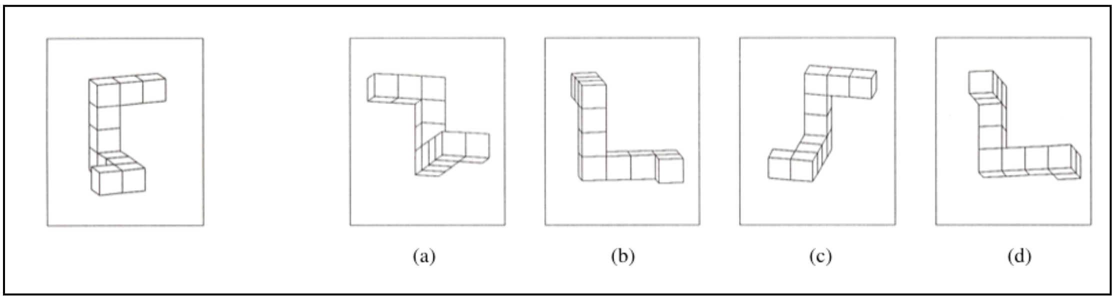

Figure 1. An example item from the MRT showing the target figure (on the left) and four comparison figures (on the right). Figures (b) and (c) match the target.

Materials

Three questionnaires assessed stress at baseline before fanning (Questionnaire 1), after fanning (Questionnaire 2), and after the MRT (Questionnaire 3) using the items: How would you rate your stress level right now (1 = not stressed at all, 9 = very stressed)? How tolerable is your feeling of stress right now (1 = not tolerable at all, 9 = very tolerable)? Right now, is your stress level lower or higher than it usually is (1 = lower than usual, 9 = higher than usual)? How relaxed do you feel right now (1 = not relaxed at all, 9 = very relaxed)? The items in Questionnaire 3 were re-worded to refer to participants' experience during the MRT. For example, the item, "How would you rate your stress level *right now*?" became, "How would you rate your stress level *during the spatial intelligence task*?".

Ratings on these four items were averaged (reverse-scored where appropriate so that higher scores on the composite reflected higher stress) to create a stress composite score for each time point for data analysis (Cronbach's alpha = .68, .79 and

.72 for Questionnaires 1, 2 and 3, respectively). These new variables were screened and one outlier (with a z score of -3.30, exceeding the 3.29 cut-off recommended by Tabachnick and Fidell, 2007) was removed from the control condition for Questionnaire 3. The Shapiro-Wilk test indicated that these composite variables were normally distributed (all *p*s > .06).

Three additional items were included in these questionnaires: Right now, does it seem like the thoughts passing through your mind are moving slower or faster than they usually move (1 = slower than usual, 9 = faster than usual)? Are you in a good or bad mood right now (1 = very good mood, 9 = very bad mood)? How strong is this emotion (1 = not strong at all, 9 = very strong)? These items were included out of interest only and were not analysed in this study.[1]

Four additional items were included in Questionnaire 1 to allow us to examine whether trait stress and enjoyment of spatial intelligence problems moderated the effect of cooling on stress during the MRT: Over the course of the past two weeks, how stressed have you been feeling (1 = very relaxed, 9 = very stressed)? Over the course of the past two weeks, how quickly have you been able to relax after stressful experiences (1 = not at all quickly, 9 = very quickly)? Do you tend to become stressed easily (1 = not easily at all, 9 = very easily)? How much do you enjoy spatial intelligence problems like the one below (1 = not at all, 9 = very much)? This last question was followed by an example problem from the MRT.

The fourth and final questionnaire (Questionnaire 4) assessed basic demographics (gender, age, height, native language, and years spoken English for those with a different native language) and participants' experience during fanning using the questions: How did you find the noise of the fans (1 = unpleasant, 9 = pleasant)? How did you find the airflow from the fans (1 = unpleasant, 9 = pleasant)? Questionnaire 4 also included a number of exploratory items that were not analysed in the present study. Copies of the four questionnaires are provided in Appendix B.

Results

Manipulation Checks

First, we examined whether head fanning did in fact reduce brain temperature, as indicated by ear temperature. To do this, the left and right ear temperature

[1] There was no effect of condition on these variables (all *p*s > .40).

measurements were averaged at each time point (before fanning, after fanning) to minimise the impact of asymmetrical temperatures (see Boyce et al., 2002). One outlier (with a *z* score of -3.52) was deleted from the cooling condition after fanning. As shown in Table 1, the mean (and standard deviation) for ear temperature after fanning was 36.51 (0.32) for the cooling condition and 37.06 (0.25) for the control condition. This difference was statistically significant when controlling for ear temperature before fanning using a one-way between-groups ANCOVA, F (1,87) = 258.01, $p < .001$, partial eta squared = .75. As expected, ear temperature was reduced in the cooling condition relative to the control condition. Head fanning therefore appeared to work as intended. Room temperature and humidity did not moderate this effect (both *p*s > .19).[2]

We then examined whether participants found the MRT stressful using a paired-samples t-test. Stress composite scores increased significantly from before (M = 3.87, SD = 1.29) to after the task (M = 5.74, SD = 0.98), t (89) = -13.32, $p < .001$ (one-tailed), eta squared = 0.67, with a mean increase in stress scores of 1.87 (95% CI = 1.59: 2.15). This confirmed that participants found the task stressful and that it was therefore appropriate for investigating the effects of head fanning on stress.

Table 1. Means (and standard deviations) for measures of ear temperature, stress, and task performance in the two conditions.

	Ear Temperature		Stress			Task Performance	
Condition	Pre-fanning	Post-fanning	Pre-fanning	Post-fanning	Post-task	Number Correct	Number Attempted
Control	37.00	37.06	4.28	3.82	5.97	4.98	10.58
(*n* = 48)	(0.26)	(0.25)	(1.21)	(1.25)	(0.87)	(2.87)	(3.98)
Cooling	36.98	36.51	4.26	3.89	5.48	6.44	10.72
(*n* = 43)	(0.31)	(0.32)	(1.08)	(1.36)	(1.04)	(3.54)	(4.77)

Main Analyses

Cooling effects on stress

We hypothesised that head fanning would buffer stress during the spatial intelligence task (Hypothesis 1). That is, we expected (a) that cooled participants would be less stressed during the task than control participants and (b) that this difference would not be due to a direct effect of the fanning procedure on stress,

[2] See the Other Moderators section below for the procedure used in these analyses.

evidenced by comparable stress levels between conditions immediately after fanning. This was tested using two one-way between-groups ANCOVAs with fanning condition (cooling, control) as the independent variable, stress composite scores (from either Questionnaire 3 or Questionnaire 2, respectively) as the dependent variable, and baseline stress composite scores as the covariate.

As shown in Figure 2A, after adjusting for baseline scores, participants in the cooling condition (adjusted $M = 5.49$, $SE = .14$) were significantly less stressed during the task than participants in the control condition (adjusted $M = 5.97$, $SE = .14$), F (1, 87) = 5.94, $p = .02$, partial eta squared = .06. As expected, cooling reduced stress during the task. Furthermore, this was not due to a direct effect of the fanning procedure, as there was no significant difference in stress scores after fanning between the cooling (adjusted $M = 3.89$, $SE = .18$) and control (adjusted $M = 3.82$, $SE = .17$) conditions, F (1, 88) = 0.09, $p = .76$, partial eta squared = .001 (see also Table 1). As expected, participants in the cooling condition were less stressed during the task and this was not due to a direct effect of the fanning procedure on stress levels. This supports the hypothesised stress-buffering role of cooling.

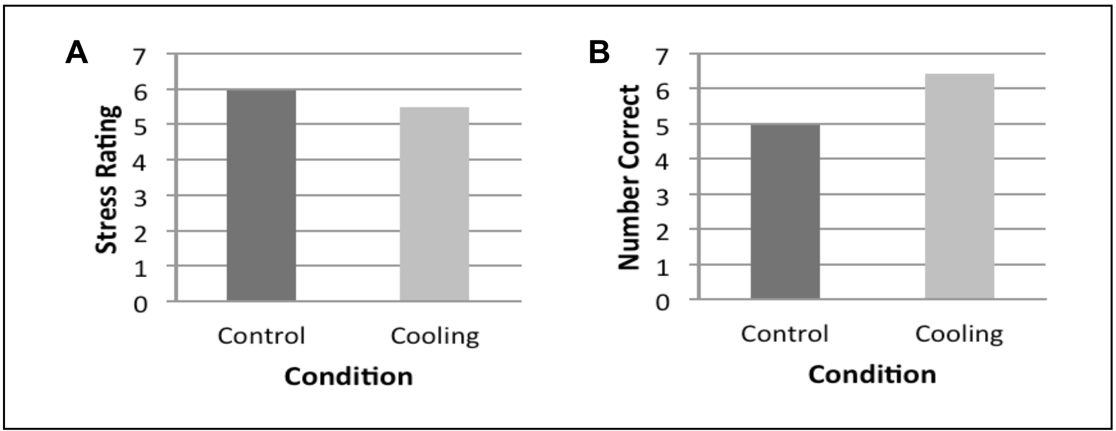

Figure 2. Mean stress (A) and performance (B) during the task by condition.

Mediation of cooling effects on stress

We hypothesized that head fanning would buffer stress due to a reduction in brain temperature, as indicated by ear temperature (Hypothesis 2). To examine this hypothesis, we first calculated the change in ear temperature during fanning by regressing post-fanning temperature on pre-fanning temperature (i.e., partialing out pre-fanning temperature). The unstandardized residual produced represents the post-fanning ear temperature controlling for the pre-fanning ear temperature (see Martens et al., 2010). The correlations between this and the other main variables are reported in Table 2.

Table 2. Correlations between measures of ear temperature, stress, and task performance.

Measure	1	2	3	4	5	6	7
1. Pre-fanning temperature	-	**.601** **	.000	.172	.070	.133	-.067
2. Post-fanning temperature		-	**.799** **	.141	.041	**.317** **	-**.266** *
3. Temperature change residual			-	.026	-.001	**.289** **	-**.283** **
4. Pre-fanning stress				-	**.463** **	.230 *	-.024
5. Post-fanning stress					-	**.341** **	-.167
6. Post-task stress						-	-.172
7. Task performance (number correct)							-

Significant correlations are in bold. * $p < .05$ (2-tailed). ** $p < .01$ (2-tailed).

We then computed a simple mediation model to examine whether this ear temperature residual mediated the relationship between condition and stress during the task using a non-parametric approach developed by Preacher and Hayes (2004, 2008). In this analysis, condition was the independent variable, stress during the task was the dependent variable, and residualized ear temperature was the mediator.[3] Baseline stress was controlled for by entering it as a covariate. Using the macros provided (Preacher & Hayes, 2008), a bootstrapping procedure based on 5000 samples was used to estimate a 95% bias-corrected and accelerated confidence interval (BCa; Preacher & Selig, 2012) around the indirect effect (i.e., the effect of condition on stress through the mediator, ear temperature). The indirect effect is considered statistically significant when this confidence interval does not include zero. This method is recommended over the traditional Baron and Kenny (1986) and Sobel (1982) tests of mediation when dealing with small sample sizes like ours because these tests require large samples to achieve adequate power and to meet key assumptions respectively, which would increase the likelihood of Type II error in the present analysis (Frazier, Tix, & Barron, 2004; Hayes, 2009; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). However, for the sake of convention, we also

[3] We decided to use temperature change instead of post-fanning ear temperature as the mediator in this analysis to be consistent with the dependent variable, stress, which was also a change score (from baseline). This decision was not clear-cut, however, so we also computed the mediation model using post-fanning temperature as the mediator. The results were essentially the same.

report the unstandardized regression coefficients required for testing mediation according to Baron and Kenny's (1986) causal steps method and the results of the Sobel (1982) test (see Preacher and Hayes, 2004, for explanation of these methods).

As shown in Figure 3, cooling reduced ear temperature (b = -0.54, p < .001) but this did not predict differences in stress during the task when controlling for condition (b = 0.71, p = .28), although this relationship was in the expected direction (i.e., as ear temperature reduced, so did stress). In addition, condition was a significant predictor of stress when ear temperature was absent from the model (b = -0.50, p = .01) but when the mediator was included this direct path was no longer significant (b = -0.12, p = .76). Although this pattern of results is suggestive according to Baron and Kenny's (1986) criteria, the fact that zero fell inside the 95% BCa confidence interval (-1.15 to 0.30) indicated that the mediation effect was not significant. The Sobel test, which also tests the significance of the mediation effect, supported this (z = -1.10, p = .27). Thus, although cooling reduced subsequent stress during the task, our results do not clearly support the hypothesis that this was mediated by a reduction in brain temperature, as indicated by ear temperature (Hypothesis 2). This unexpected finding can be interpreted in two ways: either (a) brain temperature did mediate the effect of condition on stress but we could not measure it accurately, or (b) brain temperature was not involved and some other difference(s) between conditions was responsible for the lower stress levels of cooled participants during the task. We will examine these two possibilities in the Discussion.

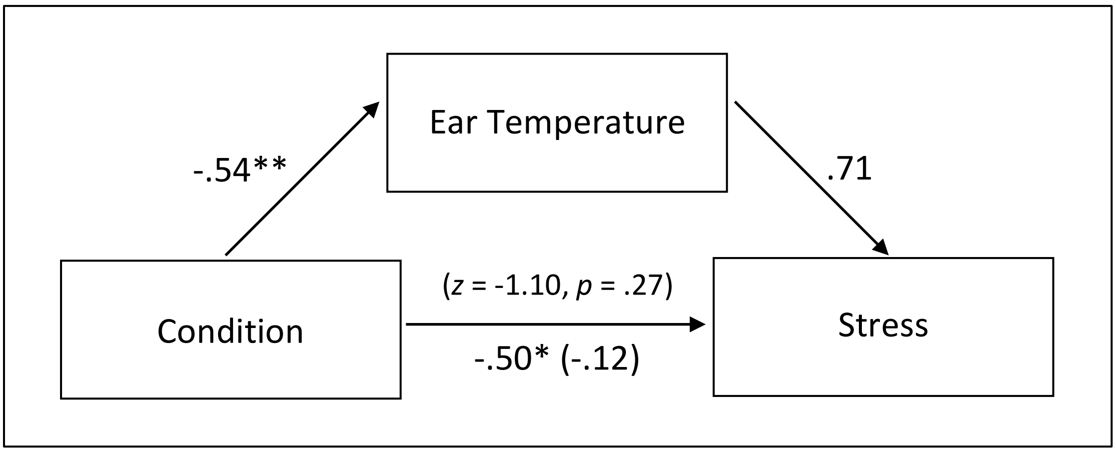

Figure 3. Ear temperature change as a mediator of the relationship between condition and stress during the task. Path coefficients are unstandardized beta weights. The beta weight for the relationship between condition and stress when controlling for ear temperature is in parentheses. The z-value (and associated p-value) refers to the Sobel test result. Results were controlled for baseline stress. * p < .05 and ** p < .01.

Ancillary Analyses

Cooling effects on performance

Although not hypothesised, we also examined the effect of fanning condition (cooling, control) on spatial intelligence task performance, measured as the number of items correct, using a one-way between-groups ANOVA. As shown in Figure 2B, participants in the cooling condition ($M = 6.44$, $SD = 3.54$) got significantly more items correct than those in the control condition ($M = 4.98$, $SD = 2.87$), $F(1, 89) = 4.73$, $p = .03$, eta squared = .05. This analysis was then repeated using the number of items attempted on the spatial intelligence task (i.e., how quickly participants worked through the problems) as the dependent variable to test whether this result was simply due to a difference in the speed-accuracy trade-off (Fitts, 1954) between conditions. For example, cooling might have slowed people down so that they attempted fewer questions but got more right, thus increasing the number of items correct. However, as shown in Table 1, there was no significant difference in the number of items attempted between the cooling ($M = 10.72$, $SD = 4.77$) and control conditions ($M = 10.58$, $SD = 3.98$), $F(1, 89) = .02$, $p = .88$, eta squared = .00. This means that the improved performance of participants in the cooling condition was not due to differences in the speed of response. Therefore, in addition to being less stressed during the spatial intelligence task, participants in the cooling condition also did better than those in the control condition.

Mediation of cooling effects on performance

To examine whether the relationship between condition and task performance was mediated by residual ear temperature, we computed a simple mediation model as before. The pattern of results was similar to the model for stress. As shown in Figure 4, the reduced ear temperature of participants in the cooling condition ($b = -0.54$, $p < .001$) again failed to predict differences in task performance when controlling for condition ($b = -3.67$ $p = .09$). This relationship did however approach significance and was in the expected direction (i.e., as ear temperature reduced, performance increased). Condition was also a significant predictor of task performance when ear temperature was absent from the model ($b = 1.47$, $p = .03$) but not when it was included ($b = -.53$, $p = .70$). Nevertheless, as with stress, the 95% BCa confidence interval included zero (-0.52 to 4.31), indicating that, despite this pattern of results being suggestive, the indirect effect was not statistically significant and that ear temperature did not mediate the effect of cooling on task performance. The Sobel test supported this (z = -1.73, p = .08).

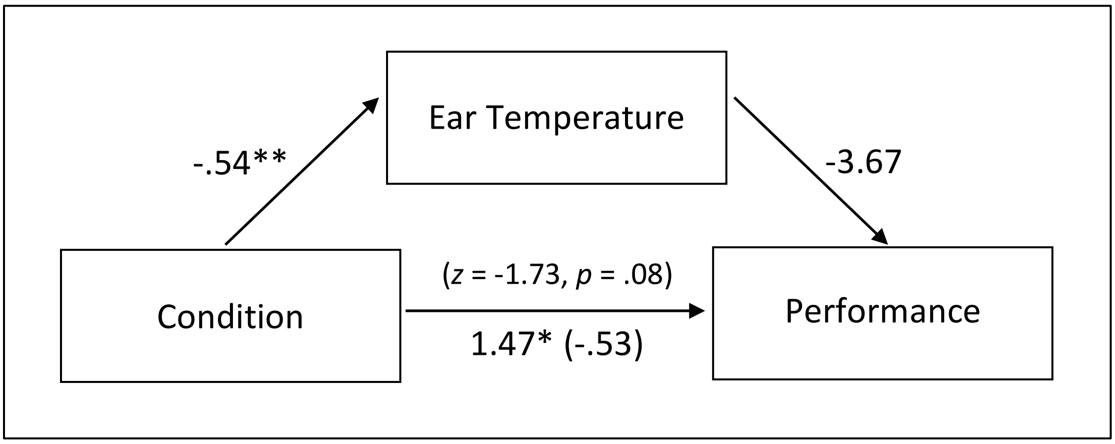

Figure 4. Ear temperature change as a mediator of the relationship between condition and task performance. Path coefficients are unstandardized beta weights. The beta weight for the relationship between condition and performance when controlling for ear temperature is in parentheses. The z-value (and associated p-value) refers to the Sobel test result. * $p < .05$ and ** $p < .01$.

Testing the interrelationship between stress and performance

Participants in the cooling condition were less stressed and performed better during the spatial intelligence task. These outcomes may have been related, as stress and performance are known to influence each other (e.g., Muse, Harris, & Feild, 2003). Thus, cooled participants may have either (a) performed better on the task because they were less stressed (i.e., cooling improved performance *because* it reduced stress) or (b) were less stressed because they performed better on the task (i.e., cooling reduced stress *because* it improved performance). Alternatively, the beneficial effects of cooling may have been independent. Two mediation analyses were conducted as before to examine these possibilities. Baseline stress composite scores were entered as a covariate in these analyses. However, the 95% BCa confidence intervals included zero when testing both stress (-0.09 to 0.70) and performance (-0.20 to 0.02) as mediators. The reduced stress and improved performance of cooled participants during the task therefore appeared to be independent.

Gender effects

We then checked for the presence of a gender effect in this study. A series of 2 (cooling, control) by 2 (male, female) between-groups ANCOVAs and ANOVAs showed a significant main effect of gender on both stress and performance, respectively. Men were less stressed (men = 5.16 ± 0.97; women = 5.97 ± 0.89), F (1, 85) = 10.95, p = .001, partial eta squared = .11, and also performed better (men = 6.92 ± 3.93; women = 5.17 ± 2.85), F (1, 87) = 4.88, p = .03, partial eta squared = .05, than women during the task. However, there were no significant interaction effects (all ps > .30) and controlling for gender did not alter the significance of the mediation analyses, indicating that gender did not affect any of the results reported above.

Other moderators

Finally, we examined whether the additional variables outlined in the Method section (three trait stress items and one enjoyment of spatial intelligence problems item) moderated the relationships between fanning condition and stress and performance reported above. Because these variables were continuous, moderation was tested using hierarchical multiple regression. A dummy-coded variable that represented fanning condition (0 = control, 1 = cooling) and the mean-centered moderator variable of interest were entered in the first step, and the interaction between the two was entered in the second step. Mean-centered baseline stress composite scores were controlled for when examining stress by entering them separately before the other variables (Frazier et al., 2004; Tabachnick & Fidell, 2007). None of the interaction terms from these analyses reached significance (all ps > .10), indicating that these additional variables did not moderate our earlier findings.

Discussion

Summary of Results

This study examined the novel possibility that cooling the head to reduce brain temperature reduces stress. This was based on the observation that stress increases body and brain temperature and that this kind of relationship between psychology and physiology can go both ways. After a baseline period, participants sat for 12 minutes with two running electric fans facing either toward (cooling condition) or away (control condition) from them. They then completed a stressful spatial intelligence task. Stress was assessed at baseline, after fanning, and after the task. Temperature, measured using an infrared ear thermometer, was assessed at baseline and after fanning. The results partially supported our hypotheses.

First, we hypothesised that head fanning would buffer stress responses during the task (Hypothesis 1). Our results were consistent with this hypothesis. We found that cooled participants were less stressed than controls during the spatial intelligence task, and that this was not due to differences in stress immediately after fanning. This finding is unique within psychology but is consistent with evidence from the physiological literature supporting an association between cooling and reduced stress.

Second, we hypothesised that head fanning would buffer stress because it reduced brain temperature, as indicated by ear temperature (Hypothesis 2). Our results did not support the mediation model proposed by this hypothesis. Although cooling reduced ear temperature and stress during the task (and these variables were positively correlated, as expected), stress was not significantly related to changes in ear temperature in the model.

Finally, although we had no hypotheses about task performance, we also found that cooled participants performed better on the spatial intelligence task than controls. This finding is consistent with previous research on the association between thermal stressors and cognitive performance, which has shown that slight cold can enhance performance (Hancock, Ross, & Szalma, 2007). However, as with stress, our results did not support the mediation model that ear temperature mediated this effect. Importantly, the improved performance of cooled participants in our study did not account for their reduced stress during the task, or vice versa.

Key Limitations and Future Research Directions

Although lower stress levels during the task in the cooling condition suggest a role of temperature in this effect, changes in temperature did not clearly mediate the relationship between condition and stress. This challenges the theoretical basis for our experiment: that reduced brain temperatures could buffer stress. As mentioned in the Results, this unexpected finding can be interpreted in either of two ways. First, brain temperature may have mediated the effect of condition on stress but we could not show it. Alternatively, brain temperature may not have been involved and some other difference(s) between conditions meant that cooled participants were less stressed during the task. We will examine these two possibilities below and discuss the implications for future research.

The accurate measurement of human brain temperature is a complex matter that is complicated further when dealing with healthy populations (Hlatky & Robertson, 2005). We were unable to measure brain temperature directly in the present sample because this requires invasive medical procedures. Instead, we measured tympanic temperature with an infrared ear thermometer to estimate the temperature of the brain. This method was simple, inexpensive and, importantly, non-invasive, making it appropriate for use with the healthy volunteers in our sample. However, it is not perfect and issues with its validity and reliability may have obscured the causal relationship between brain temperature and stress that we hoped to demonstrate.

First, the validity of tympanic membrane temperature as an indicator of brain temperature is debated (e.g., Brengelmann, 1993; Cabanac, 1993). In support of its use, Mariak and colleagues (Mariak, Lewko, Luczaj, Polocki, & White, 1994; Mariak, White, Lewko, Lyson, & Piekarski, 1999) and Schuhmann et al. (1999) found that tympanic temperature measured using thermocouples placed on the tympanic membrane closely followed changes in intracranial temperature measured directly in anaesthetized patients during neurosurgery. Replicating this, Mariak et al. (2003) further showed that tympanic temperature was positively and highly correlated to changes in intracranial temperature in response to face fanning in non-anaesthetized patients after neurosurgery. Although comparison of tympanic and intracranial temperatures in healthy volunteers is precluded by the invasive nature of direct intracranial temperature measurement, Mariak et al. (2003) argue that this correlation would be stronger in healthy people who lack intracranial pathologies that can impede heat transfer within the brain.

In contrast, Stone, Young, and Smith (1995) and Shiraki et al. (1988) failed to find a relationship between tympanic temperature and intracranial temperature during rapid temperature change as part of neurosurgery and in response to face fanning in a case study of a neurosurgical patient, respectively. Part of the explanation for these contradictory findings is likely attributable to the existence of temperature gradients within the brain (Mariak, 2002). Thus, tympanic temperature may indicate the temperature of one part of the brain but not another, making comparisons between studies that use different intracranial sites of measurement difficult. Consistent with this, Mariak et al. (1999) found that tympanic temperature reflected intracranial temperature in the subdural space but not between the frontal lobes and cribriform plate. Subsequently, these authors proposed that tympanic temperature might reflect global brain temperatures but be insensitive to local temperature differences within the brain, though the issue is by no means settled (e.g., Simon, 2007).

Second, there are recognised issues with the reliability of measuring tympanic temperature using an infrared ear thermometer. In a study comparing the performance of four different infrared ear thermometers to that of a thermocouple placed directly on the tympanic membrane of the opposite ear, Imamura et al. (1998) found that, despite being accurate on average, there was too much variation in measurements (SD = 0.8°C) to recommend them for clinical use. A major reason for this unreliability is improper placement of the infrared ear thermometer, resulting in a temperature measurement of part of the ear canal and not the tympanic membrane (Childs, Harrison, & Hodkinson, 1999; McCarthy & Heusch, 2006). Because of this, Heusch, Suresh, and McCarthy (2006) recommend taking three temperature measurements in each ear and using the highest of these, as the tympanic membrane is hotter than the surrounding ear tissue (Helton, 2010). Cerumen (ear wax) in the ear canal can also produce inaccuracies. We used a new disposable probe cover for each temperature measurement to reduce the impact of cerumen but only one measurement was taken in each ear.

A final issue in the present study is that surface cooling of the ear in response to fanning may have contaminated ear temperature measurements in the cooling condition. The cooler temperatures of these participants might therefore be an artefact of the cooling procedure and not indicative of brain temperature. Although we cannot discount this possibility when using an infrared ear thermometer, especially if it was not positioned accurately, it is reassuring to note that Mariak et al. (2003) have shown that the temperature of the tympanic membrane is unaffected by head fanning when it is measured directly. In this study, fanning did not just produce a reduction in tympanic temperature, as would be expected if cooling of the ear contaminated this measure. Instead, tympanic temperature reliably reflected brain temperature, regardless of whether it increased, decreased, or stayed the same (head fanning did not uniformly reduce brain temperature in this study because Mariak et al. studied neurosurgical patients who had a range of different temperature profiles and pathologies that influenced this response). This suggests that the temperature of the tympanic membrane, at least, is unaffected by surface cooling of the ear in response to fanning.

Thus, although infrared ear thermometers seem like a simple and inexpensive method of estimating brain temperature in healthy populations (like our sample), the issues with their validity and reliability leave substantial room for measurement error.

Measurement error like this can cause the effect of the mediator on the outcome variable to be underestimated in a mediation model, limiting the ability to demonstrate mediation (Frazier et al., 2004). The path coefficients in our mediation models (see Figures 3 and 4) were consistent with this, as the path between the mediator (ear temperature) and the outcome variable (stress or performance) was not significant in either model. Thus, it is possible that a reduction in brain temperature did mediate the lower stress levels of cooled participants in the present study, as hypothesised, but that our data could not show this.

The accurate measurement of brain temperature in healthy populations is therefore a major issue and one that needs to be addressed in any future research. Ideally, more direct methods of measuring brain temperature should be used. Promising non-invasive options include magnetic resonance spectroscopy, zero heat flow thermometry, and multifrequency microwave radiometry (Harris & Andrews, 2005). Of these, magnetic resonance spectroscopy, which uses magnetic resonance imaging techniques to assess temperature, is the most promising, having been used successfully to non-invasively measure brain temperature in healthy volunteers in a number of studies (e.g., Childs, Hiltunen, Vldyasagar, & Kauppinen, 2007; Harris et al., 2008; Shiloh et al., 2008). Purpose-built devices are also emerging (e.g., Children's Hospital of The King's Daughters, 2011; Dittmar et al., 2006). These methods were beyond the budget of this exploratory study. However, based on our results, we believe that a more thorough investigation of the role of brain temperature in the relationship between cooling and stress is warranted.

However, if the failure to demonstrate mediation was not due to measurement error, we must consider the possibility that brain temperature was simply not involved in the relationship between cooling and stress in this study. Consistent with this, it has been argued that fanning-induced brain cooling only occurs when people are in a state of hyperthermia, and not when temperature is normal, as in our sample (Mariak et al., 2003).[4] If this were the case, some other uncontrolled variable(s) that differed between conditions must account for the reduced stress of cooled participants. Two such variables may be white noise and experimenter bias.

An obvious difference between conditions was the magnitude of white noise generated by the fans, which would have been louder and more intense for participants in the cooling condition because the fans faced them directly (whereas the

[4] However, Harris et al. (2008) have shown that this is possible in normothermic people.

fans faced away in the control condition). Previous research on the relationship between white noise and stress is mixed, but there is evidence for a link between the two, with some studies finding that white noise increases stress (Liu, Iwanaga, Shimomura, & Katsuura, 2007; Miki, Kawamorita, Araga, Musha, & Sudo, 1998), decreases stress (Lopez, Bracha, & Bracha, 2002), or has no effect (Hartikainen-sorri, Kirkinen, Sorri, Anttonen, & Tuimala, 1991). It is therefore possible that the observed differences in stress during the task was due to differences in white noise magnitude between conditions, especially because participants may have been particularly aware of the white noise as it was part of the cover story for the experiment (i.e., participants believed that we were studying how white noise affected physiology and psychology). To investigate this, we performed an additional analysis examining participants' responses to the Questionnaire 4 item, "*How did you find the noise of the fans?*" (1 = unpleasant, 9 = pleasant) using a one-way between groups ANOVA with condition (cooling, non-cooling) as the independent variable. If differences in white noise magnitude were responsible for the different stress levels then we would expect this to be reflected in ratings on this item. However, there was no significant difference between conditions on ratings of fan noise (cooling = 5.65 ± 1.90; control = 5.67 ± 1.66), $F\ (1, 89) = 0.002$, $p = .97$, eta squared = .00, suggesting that participants' perception of white noise was similar between conditions. Furthermore, as reported in the Results, there was no difference in stress levels immediately after fanning between conditions, indicating that the differences in white noise magnitude between conditions had no direct effect on stress levels. It is therefore unlikely that white noise can account for the differences in stress observed between conditions.

A less obvious but potentially more relevant difference between conditions may have been in the behaviour of the experimenter, due to experimenter bias and, in particular, expectancy effects (see Rosenthal, 2002). Expectancy effects occur when an experimenter unintentionally treats participants differently in order to elicit responses that confirm his or her hypothesised expectations, and are especially likely when the experimenter is *not* blind to conditions, as in the present study. Thus, because the experimenter knew which condition the participants were in, he could have, for example, been friendlier toward cooling condition participants during the spatial intelligence task to minimise the stressfulness of this situation and confirm the hypothesis that participants in the cooling condition would be less stressed during the task. Consistent with this possibility, “warmer” clinicians have been shown to elicit better performance on intelligence tests than clinicians who are “cooler”, more threatening or strange (Rosenthal, 1969). Although clearly important, the experimenter in our study was not blind to conditions in order to keep the already complicated experimental procedure as simple as possible.

In summary, on the basis of this study alone, we are unable to determine whether the reduced stress of cooled participants was due to changes in brain temperature, as hypothesised, or due to some uncontrolled third variable(s), of which, experimenter bias is most plausible. To address these issues, future research should seek to reproduce the relationship between cooling and stress observed in this study using a double-blind design and, ideally, an alternative cooling method that does not produce white noise. Such alternatives include ice packs and cooling caps or helmets that are used to cool the surface of the head using conduction (as opposed to convection with fans; for a review, see Harris & Andrews, 2005). These methods have been used successfully to cool superficial regions of the brain in adult humans (Corbett & Laptook, 1998; Mellergård, 1992). As discussed above, the accurate measurement of brain temperature in healthy populations should also be emphasised in any future research.

Additional Limitations

This study has some obvious limitations beyond those discussed above. First, the majority (71%) of participants in our sample were female. Because males and females respond to stress differently (Kajantie & Philips, 2006; Taylor et al., 2000; Wang et al., 2007) and have different tympanic temperature profiles (Helton & Carter, 2011; Heusch et al., 2006) our results may not represent male responses to cooling accurately because the actual male sample size was small (n = 26). Reflecting this, the difference in stress during the task between conditions did not reach significance when examining males alone (p = .07). A larger proportion of males is necessary to examine possible sex differences in the stress-buffering effect of cooling. Unfortunately, time and resource constraints prevented us from achieving this in the present study. It also remains to be seen whether people from different age groups, professions, and cultures benefit from cooling in a similar way.

A second and related limitation is the use of self-report data to measure stress. Although self-report methods are useful for investigating subjective phenomena such as perceived stress, there are well-recognised issues with data obtained this way. The main concerns include problems with bias, socially desirable responding, and the reliability and validity of scales (Barker, Pistrang, & Elliot, 2002; Razavi, 2001). For example, women respond more extremely than men on rating scales like those used in the present study to measure stress (Crandall, 1973; Hamilton, 1968; Newcomb, Huba, & Bentler, 1986), contributing further to the issues of generalizability outlined above. Given these limitations of self-report data, it would be useful to supplement ratings of perceived stress with measures such as heart rate, which indicates sympathetic nervous system arousal during stress (Kajantie & Philips, 2006). Similarly, it was perhaps unwise to create our own stress questionnaire when established measures that have well-documented validity and reliability are available. These include the Dundee Stress State Questionnaire (DSSQ; Matthews, Joyner, Gilliland, Huggins, & Falconer, 1999; Matthews et al., 2002), the related Short State Stress Questionnaire (SSSQ; Helton, 2004; Helton, Fields, & Thoreson, 2005), and the Perceived Stress Scale (PSS; Cohen, Kamarck, & Mermelstein, 1983).

Conclusion and Implications

In summary, the conclusions that can be made on the basis of this study alone are limited. Additional research is required to replicate the stress-reducing effect of cooling observed here and to identify the causal mechanisms involved, paying particular attention to the accurate measurement of brain temperature. It also remains to be seen whether a similar effect occurs with different methods of cooling, different kinds of stress, different settings and different populations. Pending further research, then, reducing the temperature of the brain may be a simple way to reduce stress, with implications for its management.

Most obviously, cooling could help to reduce stress in performance-orientated high-stress situations like the spatial intelligence task in the present study. Students sitting exams, air traffic controllers at busy airports, and neurosurgeons operating to measure brain temperature directly might all benefit from cooling beforehand. This could be as simple as installing fans or air conditioning units aimed at head height in these workplaces. The improved task performance of cooled participants in our study suggests that cooling may also have additional benefits in these situations.

Alternatively, cooling may be useful as a general stress-management technique akin to progressive muscle relaxation (Jacobson, 1938), mindfulness meditation (Jain et al., 2007), or the relaxation response (Benson, 1975). For example, people who meditate for 10-20 minutes each day report feeling less stressed and this is reflected in stress hormones levels (Barlow & Durand, 2012; Benson, 1975, 1984). In the present study, 12 minutes of head fanning buffered stress in a stressful situation. Although it is unclear how long this effect lasts, it is possible that, used daily, cooling could reduce stress in a similar way.

Finally, our findings could have implications for the current understanding of the interrelationship between temperature and stress. Whereas stress is known to influence the temperature of the body and the brain via sympathetic nervous system arousal (Vinkers et al., 2008), the present study suggests that changes in temperature may also influence stress. We examined the therapeutic side of this and found some evidence that cooling reduces stress. The opposite, that increasing temperature could increase stress, may be worth investigating as well. Similarly, although we focused on brain temperature, changes in body temperature may also affect stress. Based on the results of this study, we believe that further research on this and other related questions in the relationship between temperature and stress is warranted.

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Appendix A – Information Sheet and Consent Form

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

INFORMATION SHEET

PSYCHOLOGICAL AND PHYSIOLOGICAL EFFECTS OF WHITE NOISE
University of Canterbury,
Department of Psychology

The experimenter and his colleagues are researching the effects of white noise on a variety of psychological and physiological measures. If you agree to participate, you will be asked to: (1) undergo a white noise exposure period (sitting between two running fans), (2) complete a short cognitive task, (3) fill out questionnaires about the task and other related psychological issues, and (4) permit the recording of physiological data, including measurement of ear temperature using an ear thermometer which will require the experimenter to come into close contact with your head. The procedure won't exceed one hour. You have the right to discontinue the experiment at any time, penalty-free, and still receive compensation for your participation.

Your privacy is completely assured. Your name will not be linked to any of the data that you generate in this study. To achieve this, the consent form with your name on it will be stored separately from the data that you provide in the course of the procedure. Furthermore, this data will only be accessed by the research team: Andrew Knox, Andy Martens and Deak Helton. Please note that an MSc (the finished product of this research) is a public document accessible via the UC library database.

If you have any questions or concerns regarding this study, please contact Andrew Knox at amk76@uclive.ac.nz or Andy Martens at andy.martens@canterbury.ac.nz.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

CONSENT FORM

PSYCHOLOGICAL AND PHYSIOLOGICAL EFFECTS OF WHITE NOISE
University of Canterbury,
Department of Psychology

I have read and understood the information sheet outlining the above-named research. By signing this form I explicitly consent to participate in the procedure with the knowledge that my data will be used in an analysis that may lead to a publication in a psychology journal. I understand that my privacy will be preserved – in other words, that my name will not be associated with any of my responses during this study.

I am aware that I may withdraw from the procedure at any time, free of penalty, and have my data disregarded and destroyed. I understand that if I do so, I will still receive class credit or compensation for the study.

Name (please print): ____

Signature: ______________________________

Date: __________________________________

Appendix B – Questionnaires

I. Stress and Mood Assessment

Stress and changes in mood are natural responses to everyday events that are experienced by everybody. Moreover, research shows that stress levels and mood change throughout the day, for a variety of reasons. Because of this, we will be asking you to rate your stress level and mood at different times over the course of the study. Please read the following questions carefully and respond by circling the number or option that most accurately represents how you feel. Please answer as honestly as possible.

1) Over the course of the past two weeks, how stressed have you been feeling?

1	2	3	4	5	6	7	8	9
Very relaxed				Neutral				Very stressed

2) Over the course of the past two weeks, how quickly have you been able to relax after stressful experiences?

1	2	3	4	5	6	7	8	9
Not at all quickly				Moderately quickly				Very quickly

3) Do you tend to become stressed easily?

1	2	3	4	5	6	7	8	9
Not easily at all				Moderately				Very easily

4) How would you rate your stress level right now?

1	2	3	4	5	6	7	8	9
Not stressed at all				Moderately stressed				Very stressed

5) How tolerable is your feeling of stress right now?

1	2	3	4	5	6	7	8	9
Not tolerable at all				Moderately tolerable				Very tolerable

6) Right now, is your stress level lower or higher than it usually is?

1	2	3	4	5	6	7	8	9
Lower than usual				Neutral				Higher than usual

7) How relaxed do you feel right now?

1	2	3	4	5	6	7	8	9
Not relaxed at all				Moderately relaxed				Very relaxed

8) Right now, does it seem like the thoughts passing through your mind are moving slower or faster than they usually move?

1	2	3	4	5	6	7	8	9
Slower than usual				Neutral				Faster than usual

9) Are you in a good or bad mood right now?

1	2	3	4	5	6	7	8	9
Very good mood				Neutral				Very bad mood

10) How strong is this emotion?

1	2	3	4	5	6	7	8	9
Not strong at all				Moderate				Very strong

II. Spatial Intelligence Question Assessment

Below is an example of a spatial intelligence question. We are interested in assessing whether this kind of problem is one you find enjoyable or not. Please look it over and answer the question below.

1) How much do you enjoy spatial intelligence problems like the one below?

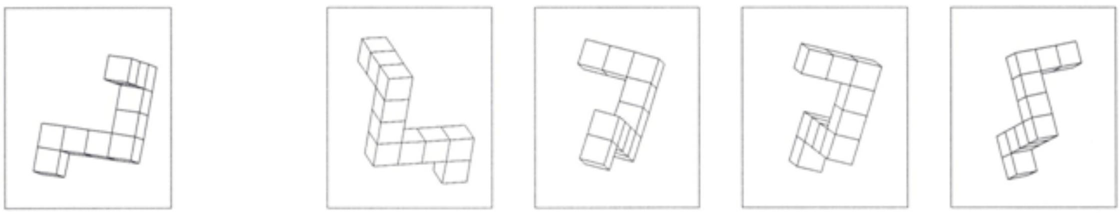
1 2 3 4 5 6 7 8 9

Not at all Moderately Very much

Now look at this object:

Two of these four drawings show the same object. Can you find those two?

1.



If you marked the first and third drawings, you made the correct choice.

I. Stress and Mood Assessment 2

For each question below, please circle the number or option that most accurately represents how you feel. Please answer as honestly as possible.

1) How would you rate your stress level right now?

1	2	3	4	5	6	7	8	9
Not stressed at all				Moderately stressed				Very stressed

2) How tolerable is your feeling of stress right now?

1	2	3	4	5	6	7	8	9
Not tolerable at all				Moderately tolerable				Very tolerable

3) Right now, is your stress level lower or higher than it usually is?

1	2	3	4	5	6	7	8	9
Lower than usual				Neutral				Higher than usual

4) How relaxed do you feel right now?

1	2	3	4	5	6	7	8	9
Not relaxed at all				Moderately relaxed				Very relaxed

5) Right now, does it seem like the thoughts passing through your mind are moving slower or faster than they usually move?

1	2	3	4	5	6	7	8	9
Slower than usual				Neutral				Faster than usual

6) Are you in a good or bad mood right now?

1	2	3	4	5	6	7	8	9
Very good mood				Neutral				Very bad mood

7) How strong is this emotion?

1	2	3	4	5	6	7	8	9
Not strong at all				Moderate				Very strong

I. Stress and Mood Assessment 3

The following questions ask about your experience during the spatial intelligence task. Therefore, for each question below, please circle the number or option that most accurately represents how you felt *during the spatial intelligence task*. Please answer as honestly as possible.

1) How would you rate your stress level during the spatial intelligence task?

1 2 3 4 5 6 7 8 9
Not stressed at all — Moderately stressed — Very stressed

2) How tolerable was your feeling of stress during the spatial intelligence task?

1 2 3 4 5 6 7 8 9
Not tolerable at all — Moderately tolerable — Very tolerable

3) During the spatial intelligence task, was your stress level lower or higher than it usually is?

1 2 3 4 5 6 7 8 9
Lower than usual — Neutral — Higher than usual

4) How relaxed did you feel during the spatial intelligence task?

1 2 3 4 5 6 7 8 9
Not relaxed at all — Moderately relaxed — Very relaxed

5) During the spatial intelligence task, did it seem like the thoughts passing through your mind were moving slower or faster than they usually move?

1 2 3 4 5 6 7 8 9
Slower than usual — Neutral — Faster than usual

6) Were you in a good or bad mood during the spatial intelligence task?

1 2 3 4 5 6 7 8 9
Very good mood — Neutral — Very bad mood

7) How strong was this emotion?

1 2 3 4 5 6 7 8 9
Not strong at all — Moderate — Very strong

8) How much did you enjoy the spatial intelligence task?

1 2 3 4 5 6 7 8 9
Not at all — Moderately — Very much

I. General Characteristics Questionnaire

1) Gender: M / F **2)** Age: ________ **3)** Height: _____ (cm)

4) At approximately what time did this session begin? ______________________

5) What is your first/native language? ________________________
If your first/native language is *not* English, please specify how long you have spoken English for: ______________________

6) Have you had a cold, flu or other similar illness in the past week? Yes / No
If yes, please specify what and whether you are still experiencing symptoms:
____
____

7) How many times do you exercise aerobically (e.g. running, swimming, rugby… any exercise that gets your heart rate up) in an average week?

0 1 2 3 4 5 6 7 8+

8) On average, when you exercise aerobically, how long do you exercise for (in minutes)? _________________________

9) Did you drink caffeine today (e.g. coffee, energy drinks)? (circle one) Yes / No
If Yes, how long ago did you finish the drink? __________________

10) Did you drink alcohol today? (circle one) Yes / No
If Yes, how long ago did you finish the alcohol? __________________

11) Have you had panadol, nurofen or aspirin today? (circle one) Yes / No
If Yes, how long ago did you take the drug? __________________

12) How did you find the noise of the fans?

1	2	3	4	5	6	7	8	9
Unpleasant				Neutral				Pleasant

13) How did you find the airflow from the fans?

1	2	3	4	5	6	7	8	9
Unpleasant				Neutral				Pleasant

14) Did you shiver at all while the fans were on?

Yes No

15) Did you mainly breathe through your mouth or nose while the fans were on?

Mouth Nose

16) Finally, briefly describe what you thought about during the 12-minute white noise exposure period.

____
____
____
____