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The cold driver: Cold stress while driving results in dangerous behavior

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ABSTRACT

Cool vehicle cabin temperatures can induce short-term non-hypothermic cold stress. The current study created a cold condition to examine the impact of cold stress on driving behavior. Forty-four participants drove a high-fidelity driving simulator during a thermal neutral or local torso cooled condition. Participants performed additional tasks to assess attention, psychomotor vigilance, and manual dexterity. Skin temperature was significantly lower in the cold condition while internal temperature was unaffected. Participants who had higher subjective ratings of cold followed lead vehicles closer and started to brake later. Participants in the cold condition followed the lead car 22% (0.82 s) closer and started braking 20% (2.35 s) later when approaching a stop sign during the car-following task. No change in attention, psychomotor vigilance, or dexterity was observed. The current results suggest that cold environmental conditions can contribute to dangerous driving behaviors. Measures of cold perception were also shown to predict changes in driving behavior.

1. Introduction

Many stressors have the potential to impact safe vehicle driving behavior (Matthews, Sparkes, & Bygrave, 1996). Stressors may stem from personal limitations such as drowsiness to environmental moderators including temperature and comfort (Melikov, Skwarczynski, Kaczmarczyk, & Zabecky, 2013; Morris, Pilcher, & Switzer, 2015; Pilcher & Huffcutt, 1996). Although thermal stressors are commonly faced by drivers, there is little research focusing on the effects of environmental temperature on driving ability. Vehicle cabins can become extreme hot or cold micro environments depending on the climate and season (Grundstein, Meentemeyer, & Dowd, 2009). Modern climate control systems can help alleviate the concern of extreme environmental temperatures, but they require time to fully stabilize the cabin temperature. During this time, the body produces a physiological and psychological response to the thermal environment that affects performance (Hancock, 1986; Rintamäki, 2007). As such, the cabin temperature can become a short-term thermal stressor that can negatively affect drivers through psychological mechanisms (Holmer, Nilsson, Bohm, & Noren, 1995).

This is an important issue for both commercial and non-commercial drivers in northern communities. In the cold winter months, non-commercial drivers may remain uncomfortably cold long after the heating system has begun to warm the cabin. This issue may be especially prevalent for drivers who live in regions where laws limit warming unattended vehicles prior to departure (Vermont statute, 2014). This occurs for two reasons. One, larger vehicle cabins require more time and energy to warm the air and surfaces (Zhang et al., 2009). Two, vehicle heating systems do not warm the cabin evenly, creating an asymmetrical thermal environment (Brooks & Parsons, 1999). As such, drivers are exposed to environments where the cabin can remain uncomfortably cold in some parts and ineffectively warm in others, negatively impacting driver comfort and thermal perception (Zhang et al., 2009). Cold temperatures also affect commercial drivers who have to frequently exit their vehicle or regularly open their cabin doors for passengers. Indeed, delivery drivers have historically complained of cold drafts associated with frequent vehicle excursions in winter months (Backman & Järvinen, 1983). An open cabin door allows warm air to escape, cooling cabin air and again encouraging an asymmetrical thermal environment. This is particularly concerning in instances where the driver may keep the cabin extra warm to account for frequent cool drafts and sweat in-between vehicle outings or cabin coolings. Frozen sweat and breath condensation can form ice against the skin inside of insulated clothing, further cooling the driver (Budd, 1989).

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Cold environments negatively impact physical and cognitive performance that is critical to safe vehicle operation through physiological and psychological stress (Bhatnagar, Mitchell, Betito, Boksa, & Meaney, 1995; Hancock, Ross, & Szalma, 2007). Cold stress has been shown to curtail attention, decision making, gross physical movement, reaction time, and dexterity relative to the intensity of the cold stressor (Parsons, 2002; Pilcher, Nadler, & Busch, 2002). In addition, uncomfortably cold temperatures increase negative affect, hostile cognition, and aggressive behavior (Anderson, 1989). When driving, aggression may manifest in several dangerous behaviors such as tailgating, hard braking, and speeding (Habtemichael & de Picado Santos, 2014; Harris et al., 2014). It is important to note that many of these negative effects occur due to perceived cooled skin temperature during non-hypothermic periods of short exposure to a cold environment. Furthermore, the perception of cold has been shown to play a role in the behavioral response to a cold stressor and to act as an indicator of intensity and discomfort in the individual (Green, 2004).

Non-hypothermic cooled skin is what most drivers would feel in a car cabin before the heating system could moderate cold cabin temperatures. Three previous studies suggest that driving in cold environments negatively impact lane keeping ability, velocity, and awareness (Chowdhury, 2015; Daanen, van de Vliert, & Huang, 2003; Norin & Wyon, 1992). However, little other research exists on the effect of cold environments on the ability to safely operate a vehicle and the findings to date are inconsistent. Particularly, few studies have explored how driving in cold environments may be affected when interacting with other vehicles.

The purpose of this study is to examine the effects of cold stress on driving performance. First, we hypothesize that cold stress will negatively impact driving behavior. More specifically, we hypothesize that individuals exposed to cold stress will drive more dangerously due to thermal discomfort resulting in faster average driving velocity and more instances of hard braking. Second, we hypothesize that cold drivers will demonstrate decreased headway when following another vehicle (i.e., tailgating). Third, we also hypothesize that perceived intensity of the cold stress will affect driving behavior such that participants reporting higher levels of perceived cold will have greater detriments in driving behavior than participants who report lower levels of perceived cold.

2. Methods

2.1. Participants

Forty-four healthy participants with an average of 4.36 years of driving experience (SD = 4.06 years) completed the study. The participants were randomly assigned to one of two groups; cold condition (10 males and 12 females, age 19.34 ± 1.13 years) and thermal neutral condition (10 males and 12 females, age 20.61 ± 4.02 years). Criteria for participation included the possession of a valid driver's license, a non-drug and excessive alcohol user, a non-smoker, in good health, a proficient English speaker, and no diagnosed history of sleep disorders. Participants admitted into the study were told to sleep eight hours on the night before their study session and to wake at least two hours before their scheduled time on the day of the study session. On the day they were scheduled to report to the laboratory, participants were told to refrain from consuming any energy supplement products, caffeine, or alcohol. In addition, participants were told to arrive at the lab wearing clothing that would offer a standardized amount of clothing thermal insulation (i.e., underwear, athletic shorts, a cotton t-shirt, and gym shoes with low socks) (Parsons, 2002). This study was approved by the institutional review board and all participants signed an informed consent before beginning the study. The study was carried out in accordance with the World Medical Association Declaration of Helsinki provisions.

The sample size of the study was set at 50 participants and based on a power analysis from a relevant meta-analysis (Pilcher et al., 2002). Pilcher established an average effect size (d) at 0.456 for short term experimental cold stress studies from 515 thermal studies. Using an error probability (α) of 0.05 and a power (1-β) of 0.9 a total sample size of 43 was calculated according to two-tailed parameters. The sample size was increased to 50 to account for participant attrition issues due to simulator sickness. Data collection stopped once 50 participants completed the study.

2.2. Materials

The driving simulator was equipped with an artificial climate control system and was integrated into a fully functioning Ford Focus cab on a pitch and longitudinal mobile base with steering wheel force feedback and a 300° five channel projection environment (DriveSafety Inc.; Murray, UT). The climate system encouraged cold stress in the cold condition by blowing room temperature air from the footwell and dash level similar to a vehicle's climate control system. The artificial climate control system was turned off during the thermal neutral condition. Room temperature was controlled using a dedicated climate control system and remained at 21 °C for all testing sessions. The driving task took approximately thirteen minutes to complete. Participants were given a training session to become familiar with the simulator by completing a three-minute driving task on a training track.

After completing the driving task participants completed a sixteen question Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993). The questionnaire addressed subjective feelings of headache, nausea, and blurred vision rated from *none* to *severe*. Six participants from the original sample size of 50 participants were removed from the study due to simulator sickness. Participants who were removed were not included in the 44 participants reported here.

Skin temperature was logged every ten seconds from four locations; lower abdomen, lower back, central hamstring, and central top of the thigh using a portable four-channel real-time data logger (Omega RDXL-4SD, Omega Engineering; Stamford, CT) with insulated wire Type-K thermocouples (Type-K, Omega Engineering; Stamford, CT). The sensors made direct contact with the skin and were insulated from the cooling apparatus using a layer of medical tape, a layer of nylon mesh over the cooling packs, as well as the participants clothing. The top of the thigh was used as a non-cooled control location to account for vasoconstriction, a physiological response indicating severity of cold stress. Estimates of internal body temperature were recorded immediately after the driving task using both an infrared tympanic thermometer (Thermoscan 5, Braun; Kronberg, Germany) and a digital oral thermometer probe (10 s, Omron; Kyoto, Japan). Subjective ratings of thermal perception (1 = Very Hot to 9 = Very Cold) and thermal comfort (1 = Very Comfortable to 5 = Very Uncomfortable) were recorded immediately after the driving task on a traditional Thermal Comfort Assessment scale (Parsons, 2002).

An adjustable nylon vest with large plastic packs filled with a phase-change material (FlexiFreeze, Mequon, WI) was used to induce cold stress. The phase-change material was a freezable liquid that acted as a heat sink to remove heat from the surface of the participant's anatomical trunk (Duffield, Dawson, Bishop, Fitzsimons, & Lawrence, 2003 ; Yifen, Nan, Wei, Guangwei, & Baoliang, 2011). The surface of the cooling packs are 0 °C when frozen and room temperature when not frozen. A single large cooling pack was also placed on the seat of the driving simulator, dexterity testing station, and PVT testing station.