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Work–rest regimens for work in hot environments: A scoping review

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Abstract

Background: To limit exposures to occupational heat stress, leading occupational health and safety organizations recommend work–rest regimens to prevent core temperature from exceeding 38°C or increasing by ≥1°C. This scoping review aims to map existing knowledge of the effects of work–rest regimens in hot environments and to propose recommendations for future research based on identified gaps.

Methods: We performed a search of 10 databases to retrieve studies focused on work–rest regimens under hot conditions.

Results: Forty-nine articles were included, of which 35 were experimental studies. Most studies were conducted in laboratory settings, in North America (71%), on healthy young adults, with 94% of the 642 participants being males. Most studies (66%) employed a protocol duration ≤240 min (222 ± 162 min, range: 37–660) and the time-weighted average wet-bulb globe temperature was 27 ± 4°C (range: 18–34). The work–rest regimens implemented were those proposed by the American Conference of Governmental and Industrial Hygiene (20%), National Institute of Occupational Safety and Health (11%), or the Australian Army (3%). The remaining studies (66%) did not

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mention how the work–rest regimens were derived. Most studies (89%) focused on physical tasks only. Most studies (94%) reported core temperature, whereas only 22% reported physical and/or mental performance outcomes, respectively. Of the 35 experimental studies included, 77% indicated that core temperature exceeded 38°C.
Conclusions: Although work–rest regimens are widely used, few studies have investigated their physiological effectiveness. These studies were mainly short in duration, involved mostly healthy young males, and rarely considered the effect of work–rest regimens beyond heat strain during physical exertion.

KEYWORDS
heat, physiology, temperature, work–rest

1 | INTRODUCTION

Climate change increasingly exposes workers to heat stress, defined as the net heat load to which a worker is exposed to due to the combination of metabolic heat (i.e., heat released from muscle metabolism depending on workload), environmental conditions, and clothing.[1] Heat strain is the overall physiological response that is dedicated to dissipating excess heat from the body (e.g., sweating and cutaneous vasodilation) that results from heat stress.[1] Inadequate exposure to heat stress (e.g., high workload, high temperature/humidity, lack of rest or personal protective equipment) may lead to unacceptable heat strain, which may affect productivity, safety, and health.[2-5] It is well-documented that heat-[6-8] and work-[2,9-11] related illnesses and injuries increase as heat stress rises (e.g., heat exhaustion, exertional heat stroke, heat-induced cardiac events, or traumatic injury due to an error of attention or judgment). It is anticipated that these risks will increase in the coming decades due to rising global temperatures. Depending on climate projection models, fatal occupational heat stroke cases (i.e., characterized by core temperature ≥40°C[1]) are expected to reach 44,084 and 64,468 cases per year in 2030 and 2050, respectively, representing one fatal case every 12 and 8 min worldwide.[12] Sectors of construction, agriculture, forestry, metal processing, and public work services, among others, are at higher risk.[3,5,13] Therefore, better protecting workers through adaptation measures that aim to limit exposures to heat stress is a crucial consideration for the management of occupational health and safety in the coming decades.

In this context, various adaptive measures are available to reduce the risk of adverse health and safety outcomes in workers,[14,15] among which engineering controls are the most cost-effective (e.g., reducing metabolic heat production with automation and mechanization,[16] shielding from radiative heat sources, and ventilation). Personal protective equipment and administrative control may also be implemented. The former refers to equipment used to prevent or minimize exposure to hazards. The latter includes strategies applied to improve workers' conditions to work safely in hot conditions, such as monitoring of weather forecasts, intelligent mobile phone applications,[17,18] training and education, strategies for improving heat tolerance of workers, and reorganization of work to reduce exposure time and workload, such as work-rest regimens.[14] Work–rest regimens, defined as a pattern of alternating work and rest periods based on an assessment of risk, represent one of the most flexible solutions, easily implemented in the field and requiring few resources.

Mainly based on Lind's work, who was the first to identify a physiological criterion for setting environmental limits while working under hot conditions,[19] the World Health Organization recommended in 1969 that: "in any case, it is considered inadvisable for the deep body temperature to exceed 38°C for prolonged daily exposure in heavy work […]" (p.18).[20] This recommendation "became the benchmark" (p.6)[21] and remains the standard guideline of many organizations such as the American Conference of Governmental and Industrial Hygiene (ACGIH),[1,21] the National Institute of Occupational Safety and Health (NIOSH),[22] and the International Organization for Standardization.[23] The Threshold Limit Values for heat-acclimatized workers and the Action Limit Values for nonheat-acclimatized workers are the most widely recommended guidelines for heat exposure in occupational settings in North America.[1] They are analogous to the NIOSH Recommended Exposure Limits and the Recommended Alert Limits, respectively. They aim to limit heat stress exposures to those where thermal equilibrium can be achieved for most workers. More specifically, they aim to "[…] maintain body core temperature within +1°C of normal (37°C) for the average person" (p.1)[21] to ensure that "[…] most workers will not have a core body temperature above 38°C" (p.3).[21] The Threshold Limit Values and the Action Limit Values are expressed as wet-bulb globe temperature for a given work intensity (kcal/h or Watts [W]). The wet-bulb globe temperature is measured in direct sunlight and considers ambient temperature, solar radiation, humidity, and wind velocity. As clothing contributes to heat stress, the wet-bulb globe temperature is adjusted by a clothing adjustment value when necessary (i.e., effective wet-bulb globe temperature). When working in hot conditions, the wet-bulb globe temperature may exceed the Threshold Limit Values or the Action Limit Values. In this case, control measures to reduce work intensity and improve the thermal environment must be prioritized to reduce heat stress and associated heat stain. If the wet-bulb globe temperature remains above the Threshold Limit Values or the Action Limit Values despite introducing control measures, it is necessary to implement a work–rest regimen. Such a measure will reduce the time-weighted average workload and the weighted average wet-bulb globe temperature if breaks are taken in a cooler environment than the workstation. Utilities that calculate work-rest ratios according to the ACGIH approach have been developed and are easily accessible.[24] However, the effectiveness of work–rest regimens does not seem to have been validated experimentally and recent studies have urged the need to refine current recommendations.[25-28] Such efforts align with recent calls from public health and occupational health and safety organizations to intensify efforts to adapt workplaces to a warming climate.[14,29,30]

An essential first step to intensify these efforts is to summarize how research has been carried out in this field and the available knowledge, which the scoping review type approach allows.[31,32] Thus, the current scoping review aims to map the existing knowledge of the effects of work–rest regimens in hot environments and to propose recommendations for future research based on identified gaps in the literature.

2 | METHODS

2.1 | Search strategy

A librarian (DA) conducted the database searches collaborating with TAD and CO for the search strategy. The following databases were searched without language restriction for relevant studies: MEDLINE (via Ovid, 1946 to December 19, 2022); Embase (via Ovid, 1974 to December 20, 2022); CINAHL Complete (via EBSCO, 1937 to December 22, 2022); Web of Science Core Collection (Clarivate, 1945 to December 22, 2022); The Cochrane Library (via Ovid, December 2022). Additionally, Dissertations & Theses Global (ProQuest), SafetyLit: Injury Prevention Literature Update, Centre d'information scientifique et technique, NIOSHTIC-2 (Publications Search), and Cochrane Work Review Group were searched for gray literature. The search strategy used text words and relevant indexing to query: Work–rest regimen while working in hot conditions. The search was last conducted on December 22, 2022. The final search strategy for EMBASE can be found in Supporting Information S1: Table 1. Cross-referencing was also performed on the reference list of all included articles and two recent reviews.[14,33] The review and the protocol were preregistered on the Open Science Framework website (https://osf.io/hnfqe).

Following the search, all identified sources were collated and uploaded into EndNote 20 (Clarivate Analytics) and duplicates were removed. Sources were then uploaded to Covidence software for the screening process in a three-stage process consisting of: (1) remaining duplicate elimination, (2) assessment of titles and abstracts, and (3) examination of full texts. The study screening was performed by two authors (TAD and HH). In the event of a disagreement, a discussion with a third author (DG) determined final decision.

2.2 | Inclusion and exclusion criteria

Sources in French and English, regardless of publication year, and that focused on work–rest regimens under hot conditions in humans were included. No exclusion criteria based on age, sex, gender, ethnicity, or health status were imposed. Studies had to address work-rest regimens (i.e., a pattern of alternating work and rest periods) under ambient conditions ≥25°C. For high humidity conditions (≥60%), studies with an ambient temperature below 25°C were also considered. However, this situation happened only once. In Seo et al.,[28] one of the four experimental conditions was performed in a 20°C environment with 80% relative humidity and additional personal protective equipment worn, resulting in an effective wet-bulb globe temperature of 30°C. Scenario studies based on predictions and that did not directly assess the impact of work–rest regimens in humans were excluded.

2.3 | Data extraction

Using double data entry, data on (1) study characteristics, (2) participants characteristics, (3) environmental conditions, (4) work–rest regimen characteristics, and (5) outcomes studied were extracted and coded in Excel spreadsheets by HH and TAD. When not provided by authors, data only available in figures were extracted using WebPlotDigitizer v 4.6 (https://automeris.io/WebPlotDigitizer).

In this review, only studies that reported data collected in humans and published in peer-reviewed journals were considered “original studies”, with subdivision of “experimental studies” and “systematic reviews.”[34] During the screening process, we found one ongoing study via https://www.clinicaltrials.gov/ (NCT05327764)[35] and contacted the authors. As the data collection was complete and all the necessary information was available, we included it in the experimental studies. Abstracts, conference/symposium papers, nonsystematic reviews, book chapters, technical reports, and recommendations/guidelines were considered separately as “other sources.”

Then, the studies were classified according to their geographical location. To do this, we used the information presented in the text (direct mention of the place where the data collection was carried out or direct mention of the institutional ethics committee) or the address of the corresponding author. The corresponding human development index value was obtained using the United Nations Development Program (https://hdr.undp.org/data-center/human-development-index#/indicies/HDI).

When not reported, body mass index was computed. Wet-bulb globe temperature was estimated using recommended equations[1] from dry- and natural wet-bulb temperature data for studies without radiation in which case dry-bulb temperature is considered equivalent to globe temperature (i.e., 0.7 × wet-bulb temperature + 0.3 × dry-bulb temperature) and by considering globe temperature when applicable (0.7 × wet-bulb temperature + 0.2 × globe temperature + 0.1 × dry-bulb temperature). When relative humidity was not reported, but wet-bulb temperature was available alongside ambient temperature, relative humidity was estimated using a free online relative humidity calculator (https://www.1728.org/relhum.htm). Finally, for studies where rest periods were taken in different environments, the time-weighted average of wet-bulb globe temperature, ambient temperature, and relative humidity were calculated.

Arithmetic averages (±SD and range) were computed to estimate mean age, mean ambient conditions (wet-bulb globe temperature, ambient temperature, relative humidity, and air velocity), mean protocol duration, and mean number of participants per study across the included sources. To do this, we considered one value per study, or one value per subgroup when the study included different age groups, different environmental conditions, different protocol durations or combinations of these.

Studies were categorized according to the type of task performed, that is, physical or mental task only. When a study used both physical and mental tasks, it was categorized as "physical and mental, sequentially" when physical and mental tasks occurred one after the other or "physical and mental, concurrently" when both tasks when performed simultaneously. Among the three field studies included, two involved the monitoring of real-world work scenarios including an occupational task with high cognitive and physical demands (e.g., agriculture, construction, and tourism in Ioannou et al.,[16] and welding in Attia & Engel[36]). Consequently, these studies were included in "physical and mental, concurrently." The third field study was categorized as "physical only." In this study, participants were exclusively engaged in walking.[37] Physical tasks were classified as follow: endurance, maximal force/power/speed, and psycho-motor.[38] The intensities reported are exercise intensities and not time-weighted intensities that consider rest periods. Nonetheless, for studies that used varying exercise intensities over a given work period, we applied the time-weighted average technique. Finally, in the retrieved and included studies, various methods were used to set and report work intensity. Considering the descriptive nature of a scoping review, we decided to categorize the studies according to the different methods used. However, for studies in which the participants worked at a given metabolic rate, different intensity units were reported between studies, with sometimes multiple units reported in a given study. In this case, we decided to present the unit used by the greatest number of studies (W).

The goal of the ACGIH guidelines is to prevent heat-related illnesses by ensuring that core temperature does not exceed 38°C or increases <1°C from resting core temperature.[1] Therefore, for each study we checked (when reported) whether individual or average core temperature values exceeded these thresholds. This allowed us to determine the proportion of studies where these thresholds were exceeded. Some authors have extrapolated core temperature data to longer shifts. We did not take these extrapolations into account and retained only the measurements.

Throughout the text and figures, the symbol *k* represents the number of sources while the symbol *n* represents the number of participants.

3 | RESULTS

3.1 | Included studies

Figure 1 depicts the flowchart showing the study inclusion process. The initial databases search yielded 1469 articles, from which 476 duplicates were removed. Fifty-six sources were retained for full-text screening, to which 28 sources were added from cross-referencing. In the end, 49 sources met the inclusion criteria, of which 35 (71%)

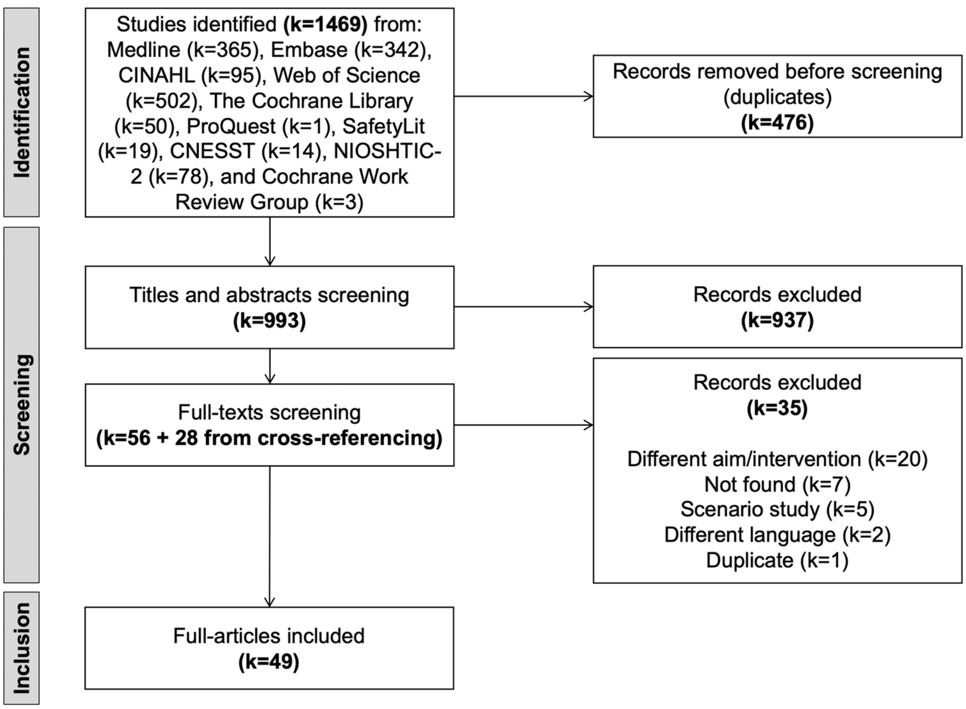

FIGURE 1 Flowchart showing the selection process used for the inclusion and exclusion of studies. CNESST, Centre d'information scientifique et technique.

were original studies[16,26–28,35–37,39–66] and 14 other sources: five technical reports,[14,67–70] three reviews,[71–73] two guidelines,[21,22] two book chapters,[74,75] one symposium paper,[76] and one abstract.[77] No Cochrane review, systematic review, nor meta-analysis was found.

Figure 2 presents the geographical and temporal distribution of the included sources. The sources included cover 67 years. The 35 original studies were all experimental studies published between 1956 and 2023 (Figure 2A) in 17 different journals. Data per country are presented in Figure 2B. They originated from high or very high human development index countries, mainly in North America ($k = 25$, 71%), Europe ($k = 5$, 14%), Australia ($k = 2$, 6%), and Africa ($k = 2$, 6%). One study investigated workers from two continents, Europe and Asia.[16] There was some overlap between authors, with nine (Kenny, Canada), three (Kamon, USA), three (Lind, UK), two (Kraning & Gonzalez, USA), and two (McLellan, Canada) studies coming from the same teams, highlighting how few researchers have worked on this topic. After the first retrieved experimental study in 1956, there were three periods (1964–1972, 1994–2000, and 2002–2010) during which literature contribution to the topic ceased for approximately 10 years (number of experimental studies ≤1 per decade) (Figure 2A). About half of the experimental studies (17 out of the 35 studies) were published between 2011 and 2023. Of the other sources, three were published between 1979 and 1984, one in 2003 while the majority (71%) were published from 2010 onwards. They also originated from high or very high human development index countries (Figure 2C), mainly in North America ($k = 10$, 71%), Europe ($k = 3$, 23%), and Asia ($k = 1$, 8%).

3.2 | Studies characteristics

Of the 35 experimental studies included, 32 (91%) were conducted in laboratory settings using environmental chambers, while only three (9%) were conducted in the field (welding[36]; agriculture, construction, tourism[16]; military context[37]) (Figure 3A). Two laboratory studies tried to increase ecological validity by adding artificial radiation[47] or by simulating mining work in a blacked-out environmental chamber with underground noises recorded on a tape.[53] The number of participants included in the experimental studies varied between 1 and 115 (median: 10), for a total of 642 participants (representing an average of 18 ± 25 participants per study). Only six studies[35,40,45,49,58,66] included females (total of 38, 6%) (Figure 3B). No studies focusing only on females were retrieved. The menstrual cycle was either controlled,[35,40,58,66] uncontrolled[45] or nothing was specified about it.[49] Nine studies (26%) included heat-acclimatized participants, 18 (51%) were conducted on nonheat-acclimatized individuals and eight (23%) did not mention the acclimatization status of the participants (Figure 3C). The average age of the participants was 33 ± 12 years old (median: 27, range: 21–63). Most of the experimental studies recruited young adults (Figures 3D) and seven (20%) included different age groups. Among these seven studies, five compared two or three age groups with each other[39,43,44,51,53] and two included participants belonging to different groups without comparison.[16,50] It is important to note that 30 studies (86%) focused on healthy participants, whereas the remaining five studies (14%) did not provide information about the health status of the participants. All the included studies investigated participants with body mass index <30 kg/m^2 (Figure 3E). None of the studies mentioned details about ethnicity. Additionally, 14 of the 35 studies (40%) restricted their participants from consuming coffee and alcohol the day before experimental visits, while the remaining studies did not mention such details (60%).

The time-weighted average wet-bulb globe temperature was 27 ± 4°C (median: 28, range: 18–34). The time-weighted average ambient temperature and relative humidity were, respectively, 35.0 ± 6.0°C (median: 35.0, range: 20.0–50.0) and 44 ± 18% (median: 47, range: 10–84). One of the included studies investigated the separate and combined effects of thermal and pollutant stress.[43] Twenty-five of the 35 experimental studies (71%) included participants working and resting in the same environmental conditions, eight (23%) had participants resting in cooler environmental conditions compared with work, and two (6%) compared both scenarios. Only four of the 35 studies (11%), including three field studies, mentioned the presence of radiant heat. Only one laboratory study used an artificial radiant heat source.[47] Sixteen of the 35 studies (46%) mentioned the absence/presence of air velocity (0.8 ± 0.8 m/s, median: 0.8, range: 0–3.6), whereas the remaining studies did not mention values for air velocity.

Most experimental studies (31 out of 35; 89%) reported details about the clothing worn. Among those that reported this information, only seven reported clothing insulation that ranged from 0.031 (0.20 Clo)[66] to 0.327 (2.11 Clo)[37] m^{2}K/W, with only two studies >0.155 m^{2}K/W (i.e., >1 Clo), both in a military context.[37,40] The remaining 24 studies only provided details about the type of clothing worn and their materials. Five studies specifically used restrictive clothing (e.g., semipermeable chemical protective overgarments).

Regarding hydration, 17 (49%) of the included experimental studies allowed participants to drink ad libitum, four provided an absolute (L) or relative (mL/kg) amount of fluid, one provided fluids in amounts approximating sweat losses, and 1 did not report this information. Ten did not mention whether the participants could drink and two mentioned that fluid intake was not allowed due to the measurement of esophageal temperature.

3.3 | Work–rest regimens

Seven of the 35 experimental studies (20%) implemented a work–rest regimen based on ACGIH Threshold Limit Values,[26-28,39,59,60,62] none used the Action Limit Values, four (11%) used the NIOSH recommendations[35,41,45,58] and one (3%) used recommendations provided by the Australian Army[40] (Figure 4A). It is worth mentioning that seven of the studies that used Threshold Limit Values did so in participants who were not heat acclimatized[26,28,39,59] or of unknown acclimatization status.[27,60,62] Accordingly, no retrieved study has tested the Threshold Limit Values in acclimatized workers. Among the

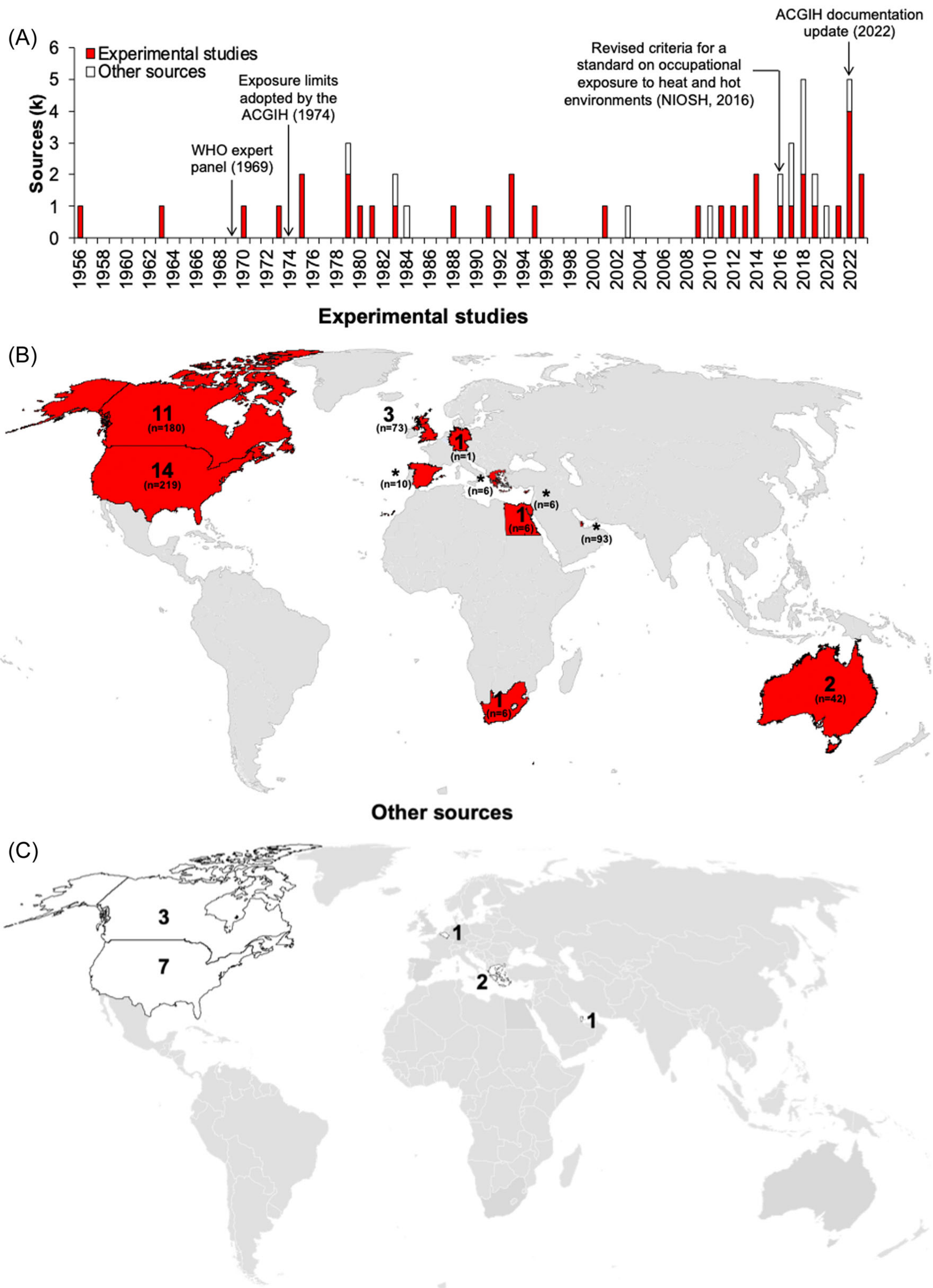

FIGURE 2 (A) Temporal distributions of the included sources. (B) Geographical distribution of the experimental studies included, with the corresponding number of participants (*n*). (C) Geographical distribution of the other sources included. *One study reported data collected on workers from four countries across two continents, Europe and Asia.[16]

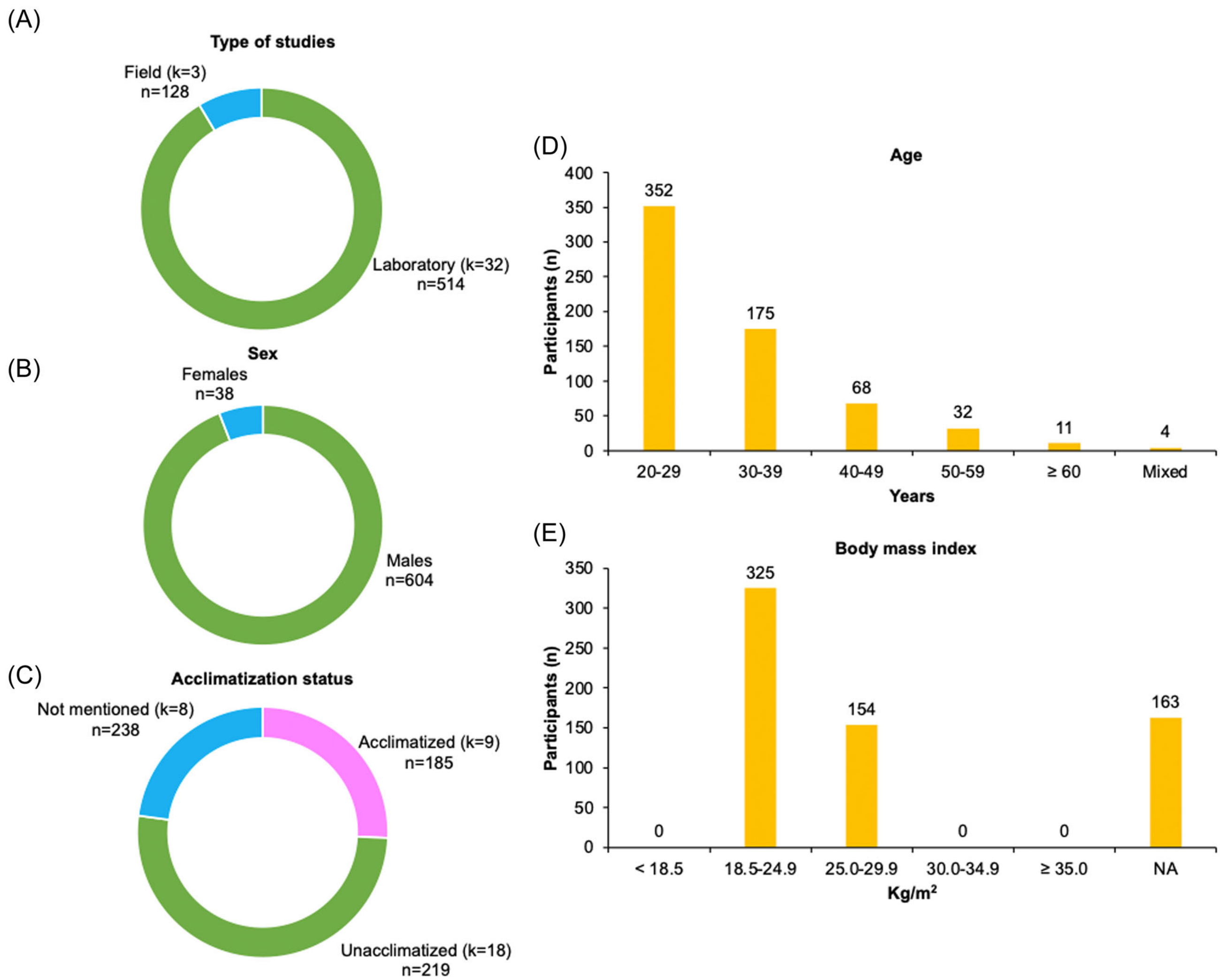

FIGURE 3 (A) Number of laboratory and field studies (*k*) with the corresponding number of participants (*n*). (B) Number of females and males in the included studies. (C) Number of studies (*k*) that investigated participants who were heat-acclimatized, unacclimatized, or that did not mention the status of heat acclimatization with the corresponding number of participants (*n*). Distribution of the 642 participants represented in the 35 experimental studies according to (D) age and (E) body mass index categories. NA, not available.

studies that used NIOSH recommendations, two specifically mentioned using the Recommended Alert Limits on unacclimatized participants,[45,58] whereas the other did not mention whether they used the Recommended Alert Limits or the Recommended Exposure Limits but investigated heat-acclimatized[41] or unacclimatized[35] participants. The remaining 23 studies (66%) did not mention on what basis the work–rest regimens were based upon. The experimental studies included could be separated into two large groups (Figure 4B), those that studied different work-rest regimens ($k = 15$) and those that studied a given work–rest regimen ($k = 20$). Of the former, 12 studies investigated different work–rest regimens for a given physical or cognitive task performed under the same environmental conditions, whereas three investigated different work–rest regimens for a given physical task performed under different environmental conditions. In the 20 studies that studied a given work–rest regimen, 12 investigated the same work–rest regimen under different environmental conditions and eight investigated a single work–rest regimen. Two studies also compared physiological responses between different age groups.

Thirty-one experimental studies (89%) focused on physical tasks only (Figure 5A), with 30 studies using endurance tasks and one study using a psychomotor task (one-dimensional vertical compensatory tracking task).[41] One experimental study (3%)[57] investigated mental tasks only (a vertical visual vigilance task), one (3%)[63] investigated endurance and mental tasks sequentially, and two (6%)[16,36] field studies investigated occupational tasks with high cognitive and physical demand (included in "physical and mental, concurrently"). No laboratory study focused on the combination of physical and mental tasks performed concurrently. Of the 33 experimental studies that investigated endurance tasks or a combination of endurance and mental tasks, 25 (76%) used a single-task such as walking,[35,37,40,43,45,47,49,50,52,59–61,63–65] cycling,[26–28,39,42,51,62,66] or block stepping.[44,48] The remaining eight

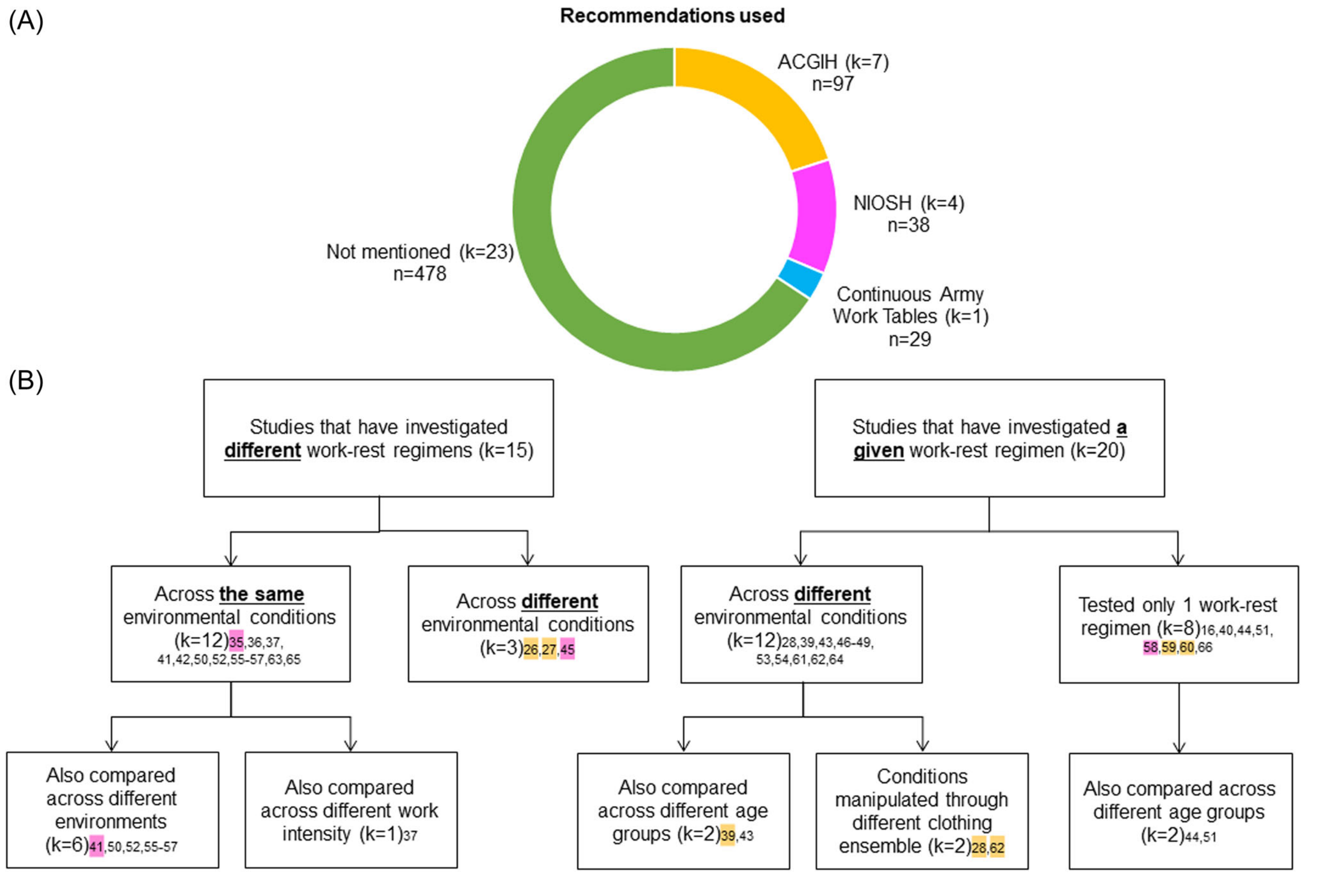

FIGURE 4 (A) Distribution of the studies (*k*) according to the recommendations used to determine work–rest regimens, with the corresponding number of participants (*n*). (B) Classification of the 35 included experimental studies based on methodological criteria. On the bottom row, the sum of the boxes does not represent the total that is presented on the middle row. The bottom row represents studies with particularities in addition to those mentioned in the middle row. Yellow and purple numbers identify the 11 studies that investigated the ACGIH (yellow) and NIOSH (purple) recommendations. ACGIH, American Conference of Governmental and Industrial Hygiene; NIOSH, National Institute of Occupational Safety and Health.

studies (24%) incorporated specific occupational tasks related to agriculture, construction, and tourism,[16] welding,[36] repetitive box lifting,[54] walking with load carrying,[49,55,56] walking with arm curls,[58] or walking with shoveling.[53] Of the 33 experimental studies that investigated endurance tasks or a combination of endurance and mental tasks, three (9%) used a self-paced strategy (one reported the associated metabolic rate measured using second-by-second time-motion or real-time analysis[16] while the other two did not report intensity data[36,54]); the remaining 30 (91%) used a fixed-pace strategy (Figure 5B). The latter used different techniques to set work intensity (Figure 5C), either by fixing exercise intensity at a given metabolic rate (*k* = 20, reporting intensity in W,[35,37,40,47,48,54,58–60] in % of VO_{2max},[42,43,49,55,64,65] in kcal/h,[44,52,53] metabolic equivalent of tasks[50] or not reported[56]), a fixed rate of metabolic heat production,[26–28,39,45,51,62,66] or fixing it at a given level of heart rate[61] or perceived effort.[63] Of the 30 experimental studies that used a fixed-intensity strategy, five used various intensity patterns during the simulated work.[40,47,49,50,53] The average total protocol duration, including work and rest periods, was 222 ± 162 min (median: 136, range: 37–660). The duration most often employed was ≤120 min (*k* = 15, 43%), with 66% of the included studies ≤240 min. More details about the specific work-rest regimens used are available in Supporting Information S1: Table 2.

3.4 | Measurements

3.4.1 | Core temperature

Of the 35 experimental studies included, core temperature data were unavailable in two studies (Figure 6A). Specifically, the study by Mortagy and Ramsey[57] did not mention the method used to record core temperature, and Beshir et al.[41] did not measure core temperature. Rectal temperature was used in 19 (58%) of the 33 studies, gastrointestinal temperature in six[16,45,58–60,63] (18%) (in two of these studies, some of the participants used rectal temperature due to specific reasons[45,59]), oral temperature in one,[36] aural canal temperature in one,[65] whereas the others used a combination of rectal and esophageal,[26,42,50,62,66] or rectal and gastrointestinal[51] temperatures. Thus, 25 (71%) of the 35 experimental studies used rectal temperature. These results provide information on whether core temperature

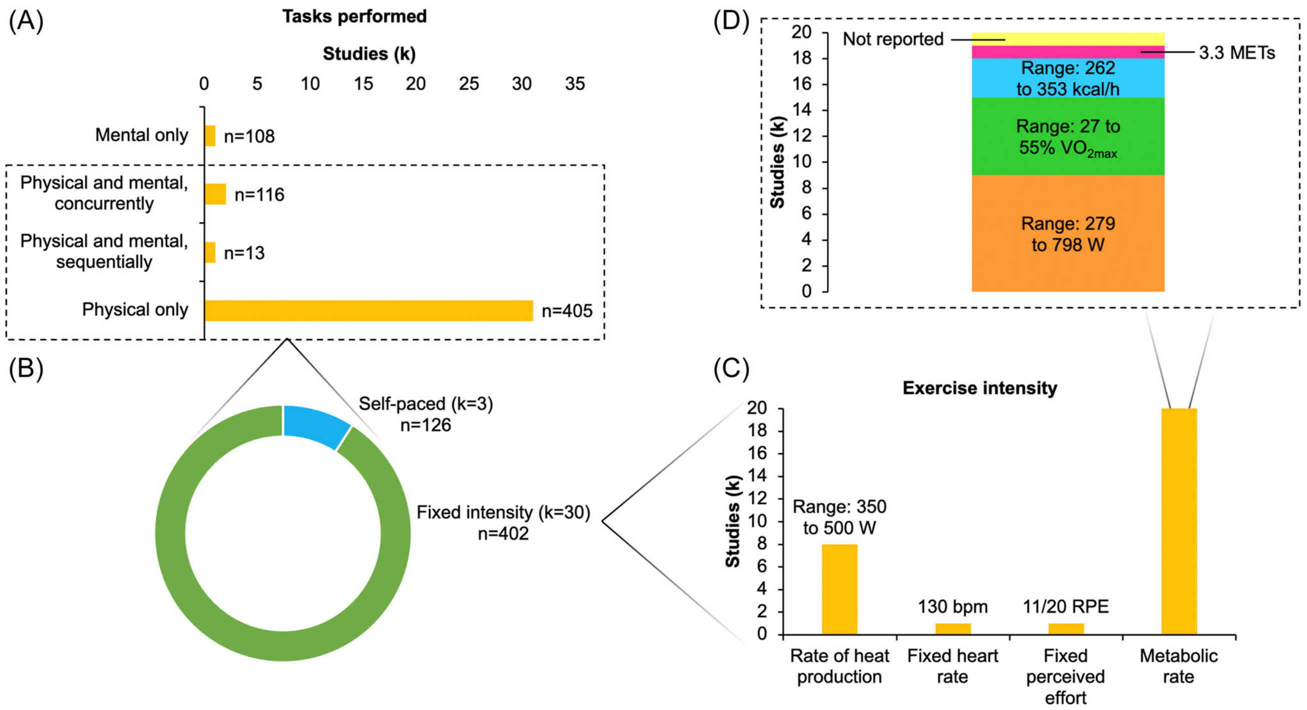

FIGURE 5 (A) Number of studies (*k*) that focused on physical tasks only, mental tasks only or a combination of both, with the corresponding number of participants (*n*). (B) Distribution of studies (*k*) that used self-paced versus fixed intensity protocols among those that focused on endurance tasks, with the corresponding number of participants (*n*). (C) Methods used to set exercise intensity among studies that used fixed-intensity protocols and the associated ranges. (D) Type of exercise intensity unit reported among studies that employed a fixed metabolic rate. bpm, beats per minute; kcal/h, kilocalories per hour; METs, metabolic equivalent of task; RPE, effort perception; VO_{2max}, maximal oxygen consumption.

exceeded 38°C or if it increased by ≥1°C compared with baseline values, which are the safety limits according to the ACGIH.[1] Of the 35 experimental studies included, 27 (77%) indicated that core temperature exceeded 38°C under different experimental conditions. In contrast, only five studies[16,36,39,51,66] reported that core temperature remained below 38°C in various conditions. The remaining three studies did not measure/report core temperature[41,57] or did not provide clear information on the level of core temperature reached during the protocol.[56] Of the 11 studies that investigated the ACGIH and NIOSH recommendations, nine (82%) concluded that current guidelines do not adequately protect workers and need further refinement.[26-28,35,45,58-60,62] For example, five studies provided data on the proportion of participants whose core temperature exceeded 38°C despite different work–rest regimens recommended by the ACGIH or NIOSH. These proportions reached 25% in Mulholland et al.[58]; 20% (exp D), 30% (exp C), and 56% (exp B) in Hess et al.[45]; 60% in Bachraty et al.[35]; 67% (WR1:1)–100% (WR3:1) in Lamarche et al.[26]; 0% (WR1:1), 11% (WR1:3), and 33% (WR3:1) in Meade et al.[27]

3.4.2 | Other physiological and perceptual outcomes

Of the 35 experimental studies included, 33 (94%) reported heart rate (Figure 6B) and 22 (63%) reported skin temperature (Figure 6C). Eleven studies (31%) measured effort perception using the 6–20 Borg Scale and one using the CR10 scale[35] (Figure 6D), and 10 (29%) measured thermal perception using category scales (7-point ASHRAE scale[26,27,42,59,60,65] and another scale[28,58]), visual analog scales,[63] or did not provide details[61] (Figure 6E). Two experimental studies (6%) reported measures of fatigue perception using the Multidimensional Fatigue Inventory[63] or a category-ratio 0–10 scale[35] (Figure 6F). Eleven (31%), four (11%), and 22 (63%) studies measured urine specific gravity, local, and whole-body sweat rate, respectively. Seven (20%) studies from the same laboratory (Kenny, Canada) used direct calorimetry to measure heat balance components.

3.4.3 | Physical and mental performance

Six (17%) and one (3%) of the 35 included experimental studies reported physical and mental performance outcomes, respectively. One study reported both physical and cognitive performance outcomes (assessed sequentially, not concurrently)[63] (Figure 7). For physical performance, Mulholland et al.[58] measured maximum oxygen consumption using a graded exercise test at the end of the work-rest protocol. Sawka et al.[37] and Uchiyama et al.[63] reported distance completed; Kraning and Gonzalez[50] reported endurance time; Maresh et al.[54] reported the total number of boxes lifted; and Smallcombe et al.[61] reported physical work capacity. In the study of Beshir et al.,[41] the participants performed a sustained

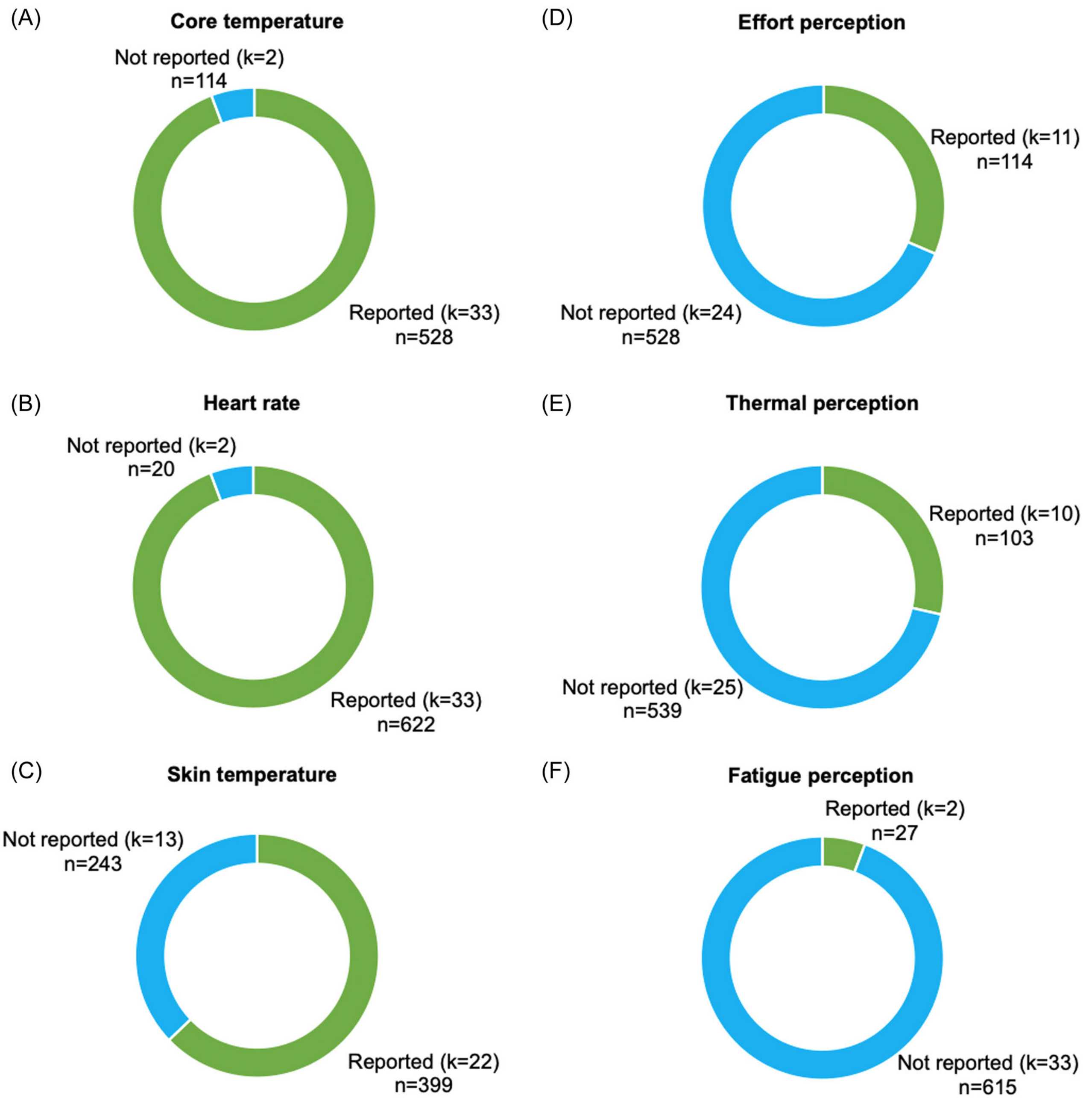

FIGURE 6 Number of studies (*k*), with the corresponding number of participants (*n*) reporting (A) core temperature, (B) heart rate, (C) skin temperature, (D) effort perception, (E) thermal perception, and (F) fatigue perception.

one-dimensional vertical compensatory tracking task where they had to maintain alignment between a vertical line and a fixed target using a hand controller. The deviation of the controlled element from the target represented the errors. Of studies addressing mental performance, Uchiyama et al.[63] measured short-term memory using a counting span task. In the study of Mortagy and Ramsey,[57] the participants performed a sustained vigilance task where they had to detect a 0.6 (short) or 1.2 (long) cm deviation (up or down) of a small dot of light displayed at the center of a screen and to discriminate between long and short signals. The proportion of correct detections and correct identifications was computed. Only one study[63] measured physical and cognitive performance as well as physiological (e.g., whole-body sweat rate, skin and core temperature, heart rate) and perceptual variables (e.g., fatigue, thermal perception).

4 | DISCUSSION

To mitigate the rising impacts of heat stress on occupational health and safety, it is urgent to enhance preventive measures and adapt workplaces. Some authors have highlighted the need to re-evaluate the effectiveness of work–rest regimens and refine current

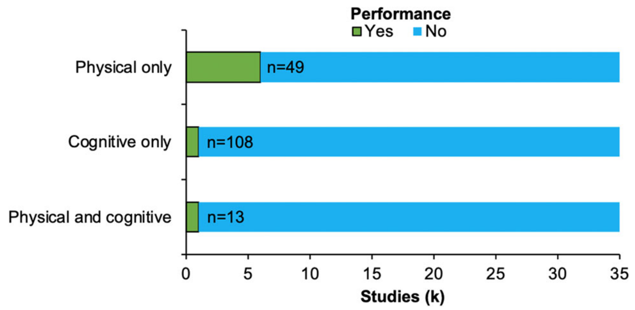

FIGURE 7 Number of studies (*k*), with the corresponding number of participants (*n*) reporting only physical or cognitive performance outcomes or the combination of both.

guidelines.[25–28] This scoping review contributes to this effort, by mapping the existing knowledge of the effects of work–rest regimens in hot environments and identifying knowledge gaps and avenues for future research. We systematically identified 49 sources: 35 experimental studies and 14 other sources. The key findings from this review are that:

(1) Most studies were conducted in laboratory settings, in high or very high human development index countries, mainly in North America, on healthy inexperienced young adults, with 94% of the 642 participants being males.
(2) Most studies simulated work using fixed-intensity treadmill walking or cycling, with 66% of the protocols ≤4 h in duration. The time-weighted average wet-bulb globe temperature was 27 ± 4°C (range: 18–34). Only 11% and 46% of the included studies mentioned the presence of radiant heat or wind, respectively.
(3) Only one-third of studies tested different work–rest regimens for a given combination of workload and environmental conditions, which is the preferred method for identifying the optimal work–rest regimen for specific conditions. Among studies that investigated the effectiveness of the work–rest regimens recommended by the ACGIH and the NIOSH, only two used this approach.
(4) Only 11 laboratory studies (31% of the included studies) investigated the effectiveness of the work–rest regimens recommended by the ACGIH or the NIOSH. Most (82%) of these studies concluded that current guidelines do not adequately protect workers and need further refinement.
(5) Almost all studies (94%) focused on thermal and cardiovascular strain, with core temperature as the main outcome. Only 22% reported physical or mental performance outcomes, which are also important to consider when trying to protect health and safety during work in the heat.

A major finding of the current scoping review is the small number of studies that investigated widespread recommendations that are easy to access and implement in the field. This is reflected primarily in the limited number of retrieved studies and the low number of studies that specifically tested the effectiveness of the work-rest regimens recommended by the ACGIH or the NIOSH. Two-thirds of the included studies did not mention the basis on which work-rest regimens were based. However, some studies mentioned that work-rest regimens were based on efficient worker rotations.[35,45,46,48] It is also possible that some studies followed protocols that the employer deemed feasible (e.g., field studies such as in Ioannou et al.[16]). The goal of the ACGIH work-rest regimens is to limit heat stress exposures to those where thermal equilibrium can be achieved for most workers, by ensuring that core temperature does not exceed 38°C or increases <1°C from resting values.[1] An important observation is that 77% of all included studies reported that core temperature exceeded 38°C under different experimental conditions. This proportion is similar (82%) when restricting this analysis to the 11 studies that directly tested the ACGIH or NIOSH recommendations. These studies suggest that current guidelines do not adequately protect workers and need further refinement. A nuance to consider is that the ACGIH or NIOSH recommendations do not claim to protect all workers, but rather "most" workers. By setting the safety limit at 38°C to protect the general population of workers, it is likely that outliers at the tail of a normal distribution (i.e., those with core temperature >38°C) will still be safe from attaining core temperatures associated with heat-related illnesses (heat exhaustion or heat stroke). In this regard, it is mentioned in the 2022 ACGIH update that: "This Threshold Limit Value has a small margin of safety and some workers may experience heat-related disorders below the Threshold Limit Value or the Action Limit Value" (p.1).[1] Nonetheless, some studies reported high proportions (sometimes ≥50%[26,35,45]) of participants with core temperature exceeding 38°C while alternating work and rest periods according to the ACGIH or NIOSH recommendations. This observation highlights a need to validate the physiological effectiveness of currently recommended work-rest regimens for work in the heat. That said, seven of the experimental studies that directly tested the ACGIH recommendations employed the Threshold Limit Values that are specific to heat-acclimatized workers. Yet, the participants in these studies were not heat-acclimatized ($k = 4$) or no details of acclimatization status were provided ($k = 3$). Heat acclimatization is a crucial factor in establishing an appropriate work–rest regimen.[1,78] For a given combination of workload, clothing, and environmental conditions, the wet-bulb globe temperature value at which unacclimatized workers must implement a work-rest regimen is 2–3°C lower than the one for heat-acclimatized workers.[1,78] According to the ACGIH, a worker is considered sufficiently acclimatized after having performed physical activity under heat stress conditions like those anticipated at work for 2 h or more, during five of the last 7 days.[1] For unacclimatized workers, the ACGIH recommends Action Limit Values. Surprisingly, the Action Limit Values have received little attention in the included studies.

The observation that 77% of all included studies reported a core temperature greater than 38°C under different experimental conditions must also be nuanced due to methodological bias. It is reasonable to believe that this observation is mainly due to the very strict protocols followed during laboratory studies, which do not allow for behavioral thermoregulation such as self-pacing. The small number of field studies included does not allow a clear comparison with laboratory studies on this criterion. Nonetheless, two of the three field studies included[16,36] do not report core temperature values exceeding 38°C, and the third is specific to a military context with very high heat stress (intensity, equipment, environment).[37] Taken together, the results from this review show that the physiological effectiveness of work-rest regimens currently recommended needs to be further evaluated and that heat acclimatization status needs to be carefully considered.

Almost all included studies (94%) focused on core temperature as the primary variable. This approach is justified since heat stroke is fatal if not recognized and treated rapidly. However, the emphasis on this single physiological variable in response to work regimens in hot environments is not without limitations. Studies show that although alternating between work and rest periods may reduce the increase in core temperature, it has a trivial effect on heart rate, skin temperature, and thermal discomfort,[26,27,42] factors known to negatively impact physical and cognitive performance.[79] High skin temperature may also challenge blood pressure regulation, increasing the risk of orthostatic intolerance during heat stress, especially in females.[80] Our review identified that few studies have tested the effect of work–rest regimens on physical and mental performance. Accordingly, there is little evidence to suggest that work-rest regimens decrease fatigue, which is thought to be responsible for increasing the risk of traumatic injuries in the workplace on hot days.[2,9-11,29] More specifically, an exacerbation of perceptual and physical strain when working in the heat may result in greater cognitive and physical fatigue.[81] Greater cognitive and physical fatigue, in turn, may increase errors of judgment and inattention, which, in turn, predispose to traumatic injuries.[81] Although a plausible link can be made between a hot environment and an exacerbation of cognitive and physical fatigue, this link is largely based on studies carried out in the context of sports performance that employed continuous exercise protocols at moderate-to-vigorous intensity (~60%–70% of VO_{2max}) with a duration ≤1.5 h, which are difficult to transfer to a work context characterized by intermittent physical tasks, of lower intensity (≤50% of VO_{2max}) and of longer duration (e.g., 4 h shifts). Some exceptions include studies that simulated military or firefighting tasks.[82-84] Determining if work-rest regimens can minimize fatigue and improve cognitive performance, in addition to mitigating the risk of heat-related illnesses, should be considered when evaluating the effectiveness of work–rest regimens for work in hot environments. In this regard, it is worth mentioning that such aspects have been reinforced in the 2022 ACGIH update: "While not considered for the Threshold Limit Value, there is also an increased likelihood of errors in judgment, acute injury, and adverse incidents with increased heat stress" (p.1).[1]

4.1 | Limitations for testing the effectiveness of work–rest regimens in hot environments

The current review has also identified key limitations of research that tested the effectiveness of work-rest regimens in hot environments upon which future research can build. First, most of the included studies involved inexperienced healthy young males in good physical condition that do not reflect the larger population of workers. More research is needed to investigate the effectiveness of work-rest regimens in hot environments for older workers, females, and individuals with pre-existing health conditions. This need stems from the observation that the proportion of older workers[85] and females[86,87] is increasing in occupational sectors that are exposed to heat. For example, females accounted for 28%, 15%, and 11% of all workers in agriculture, mining, and construction,[87] respectively, in 2021, which sharply contrasts with the 6% representation observed in the current scoping review. Similarly, the lack of studies in older adults contrast with the fact that by 2024, the labor force will grow to about 164 million people, of which 13 million are expected to be aged ≥65 years old.[85] Additionally, the prevalence of chronic diseases, such as type 2 diabetes and heart disease, is increasing.[88,89] Together, aging[90,91] and pre-existing health conditions[91–94] can reduce heat dissipation and heat tolerance, which can increase the vulnerability of these groups.[95] Notley et al.[59,60] studied the effect of sex, age, type 2 diabetes, and hypertension on tolerance to prolonged, moderate-intensity work above and below the Action Limit Values proposed by the ACGIH. The results show these factors do not affect the validity of ACGIH Action Limit Values during continuous moderate-intensity work in the heat. These studies were not included in this review because they did not specifically study work-rest regimens but rather imposed continuous work. Nonetheless, they provide a first step towards greater inclusion and diversity in this field of research, which will ultimately help protect more workers in the context of rising global temperatures.

Second, the characteristics of the protocols do not fully reflect actual working conditions in the heat. While some studies attempted to reproduce realistic working conditions, either through field studies or by implementing tasks that mimic typical tasks performed by workers, most studies suffer from low ecological validity. This is well emphasized by the fact that most of the included studies simulated work using fixed-intensity treadmill walking or cycling. Few studies employed tasks involving prolonged and repetitive use of the upper limbs. Furthermore, while the fixed-intensity approach is easier to implement in laboratory settings, it does not consider behavioral thermoregulation. In the field, workers likely self-pace their work by regulating it downwards during hot days. This suggests that studies that do not enable participants to downregulate their metabolic rate may overestimate risk and therefore be quite conservative. Furthermore, most studies only included physical tasks, and no laboratory study combined physical and mental tasks performed concurrently. In occupational settings, workers typically engage in both physical and mental tasks, including dual task, which likely increases mental load and fatigue. The latter is a common symptom, particularly in occupations with high physical or cognitive loads, or both. Finally, solar radiation was rarely considered even though it increases heat strain at a given ambient temperature, leading to impairment in physical work capacity,[96] motor-cognitive performance,[97] as well as attention and vigilance.[98]

Third, the experimental studies included in this scoping review covered a wide range of duration and intensities, but all employed acute heat exposures that were relatively short in duration relative to a typical workday (66% ≤ 4 h). This sharply contrasts with the fact that, under real settings, workers perform prolonged tasks (interspersed with a meal break) for a workday duration of ~8 h, considering a typical work week of 40 h. Furthermore, all included studies involved one exposure, which sharply contrasts with the fact that workers perform consecutive days of work under hot conditions. Indeed, some studies[60,99,100] but not all[59] observed greater heat strain on the second day of consecutive work. Therefore, the studies included in this review did not capture the potential carry-over effect of consecutive workdays in the heat over months. For most studies, participants also began simulated work in a euhydrated state, without having performed physical activities or consumed alcohol and caffeine the day before. Although these factors ensure the internal validity of these laboratory studies, they limit their ecological validity. For example, a recent meta-analysis has shown that caffeine ingestion before exercise in the heat significantly increases the rate of change in core temperature.[101] There was a large variability in how work intensity was reported, which does not allow for an adequate synthesis. We recommend harmonizing the reporting of work intensity by reporting the metabolic rate in W or kcal/h, as recommended by current guidelines.[1,24] Furthermore, more studies are needed to validate work–rest regimens for light and very high work intensities. To date, ACGIH recommendations stop at 600 W[1] or 500 kcal/h,[24] whereas certain occupations require higher workloads, particularly in industries such as agriculture and construction.[102] Currently, there are no work–rest regimens recommended for such workloads, even though very high workloads are most likely to lead to high levels of heat strain.

Finally, most studies used the wet-bulb globe temperature index to evaluate heat stress as recommended by occupational health agencies.[1,22] This index aims to account for the main heat transfer mechanisms, such as evaporation, convection, and radiation, which impact thermal sensation and strain. However, the environmental conditions used in most of the included studies only partially reflect real-world working conditions, as most of them did not consider wind or solar radiation. Solar radiation contributes to the overall thermal load and can significantly increase heat stress. Conversely, the presence of wind contributes greatly to the evaporation of sweat and, therefore, to heat dissipation. The systematic inclusion of these environmental parameters in future studies would allow for a more comprehensive understanding of the impact of work-rest regimens during work in the heat. This appears necessary since physiological and perceptual responses during a physical task are not necessarily the same for a given wet-bulb globe temperature value, depending on whether it is derived from a hot/humid environment versus a very hot/dry one.[28,103] Wet-bulb globe temperature might especially underestimate risks under conditions where sweat evaporation is restricted (e.g., high humidity, low wind speed).

The results of this scoping review should be considered with the awareness that the literature search was confined to English and French citations, thereby excluding potentially relevant studies in other languages.

4.2 | Perspectives for future studies

To further our understanding of work-rest regimens in hot conditions, the current scoping review offers the following recommendations for future research:

- There is a need to study groups that are more sensitive and vulnerable to heat, and which are underrepresented in the literature, including but not limited to females, older workers, workers with pre-existing health conditions, and workers with disabilities.
- In future studies, researchers should increase their efforts to replicate real-world conditions to adequately reflect occupational settings, especially in mimicking as closely as possible working conditions (e.g., type, duration) and ambient conditions (especially convection and radiation). More studies that directly evaluate the efficacy of work-rest regimens in the field to limit health risks are needed. Some field studies have examined regularly scheduled breaks in the shade with increased access to water and electrolyte solutions (e.g., water, rest, shade) or combined with cooling strategies (e.g., cooling vest) rather than work-rest regimens recommended by specific organizations. Thus, the true effectiveness of work–rest regimens per se, without confounding factors, remains to be better studied in the field. Furthermore, future studies should not only focus on outdoor workers. Heat stress is also present in indoor environments, and is intensified by climate change, new industrial processes, or the imposition of standards for wearing individualized protective equipment.
- It is imperative to determine whether work–rest regimens minimize the development of fatigue in a hot environment. Work typically involves the combination of repeated voluntary muscle contractions and sustained or intense cognitive tasks. It can be difficult to disentangle how fatigue is induced, that is, physically or mentally, especially because it is likely to be induced by their combination or interaction. Therefore, in future studies, the presence of fatigue needs to be evaluated with the measurement of its objective physiological (e.g., changes in power spectral density analysis of electromyography signals) or behavioral (e.g., increases in heart rate, reaction time) manifestations, with concomitant consideration of its subjective manifestations (e.g., increase in self-reported fatigue).
- Comparing the effects of different work–rest regimens under the same hot conditions is likely the best approach for identifying the most effective work-rest regimen. However, among the studies that investigated the effectiveness of the work–rest regimens recommended by the ACGIH and the NIOSH, only two employed this approach. Therefore, future research should focus on employing protocols that compare the effects of different work–rest regimens within the same environment. This will allow

for a more systematic and accurate identification of the optimal work-rest regimen for specific environmental conditions.

- In the field, workers reduce their work pace during hot days ("self-pacing," i.e., behavioral thermoregulation) and they develop a certain level of acclimatization during the summer. It is possible that the rest periods identified in laboratory settings overprotect workers in the field. While this approach is ideal for protecting workers, conservative values could potentially limit productivity. Future studies are needed to identify work-rest regimens that consider not only the health (including mental health that seems understudied in this area of research) and safety of workers but also their productivity in hot environments.
- It is well recognized that extreme heat can cause irritability, discomfort, disrupted quantity and quality of sleep patterns, as well as fatigue. Repeated exposure to these negative experiences is likely to impact workers' mental health. Unfortunately, the little literature considering the impacts of climate change on workers' mental health is scarce.[104] In this context, there is an urgent need to investigate the possible benefits of work-rest regimens on mental health. Maintaining and improving mental health in workers is of particular importance to limit presenteeism and absenteeism in the workplace.[105,106]
- Future studies and guidelines should carefully consider how core temperature is measured, as the rate of change depends on its measurement (e.g., rectal, gastrointestinal, esophageal).[107] The way core temperature results are reported varies among studies, including maximum absolute temperature reached, maximum change from a prework baseline, and time or percentage spent beyond a specific threshold. This diversity is due to a lack of consensus on risks associated with specific thresholds. To address this, future studies should focus on presenting the evolution of core temperature values over time or the rate of change, rather than just maximum absolute values or changes. This approach will help assess whether thermal equilibrium has been achieved. This approach seems necessary, because after a given work period, the average core temperature might be lower than ACGIH thresholds, yet heat balance may not have been reached. This implies that core temperature could continue to rise during more prolonged work.

5 | CONCLUSION

Although the work–rest regimens recommended by the ACGIH and NIOSH are widely used, the current scoping review shows that few studies have tested their physiological effectiveness. Extant studies were mainly of short duration (2-3 h), involved mostly healthy young males, and rarely considered the effect of work-rest regimens beyond heat strain during physical exertion. Furthermore, no retrieved study tested the Threshold Limit Values in acclimatized workers, and none tested the effectiveness of the Action Limit Values. The results from this scoping review illustrate that the effectiveness of work–rest regimens currently recommended need to be further evaluated and that heat acclimatization status needs to be carefully considered.

AUTHOR CONTRIBUTIONS

Conception or design of the work: Thomas A. Deshayes, Hsen Hsouna, Benjamin Pageaux, Capucine Ouellet, and Daniel Gagnon. *Sources search*: Thomas A. Deshayes, Denis Arvisais, and Capucine Ouellet. *Data extraction and interpretation*: Thomas A. Deshayes, Hsen Hsouna, Benjamin Pageaux, and Daniel Gagnon. *Drafting the work or revising it critically for important intellectual content*: All authors. *Final approval of the version to be published*: All authors.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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