Ambient temperature and mental health: a systematic review and meta-analysis

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Summary

Background Increasing evidence indicates that ambient outdoor temperature could affect mental health, which is especially concerning in the context of climate change. We aimed to comprehensively analyse the current evidence regarding the associations between ambient temperature and mental health outcomes.

Methods We did a systematic review and meta-analysis of the evidence regarding associations between ambient outdoor temperature and changes in mental health outcomes. We searched WebOfScience, Embase, PsychINFO, and PubMed for articles published from database origin up to April 7, 2022. Eligible articles were epidemiological, observational studies in humans of all ages, which evaluated real-world responses to ambient outdoor temperature, and had mental health as a documented outcome; studies of manipulated or controlled temperature or those with only physical health outcomes were excluded. All eligible studies were synthesised qualitatively. If three or more studies reported the same or equivalent effect statistics and if they had equivalent exposure, outcome, and metrics, the studies were pooled in a random-effects meta-analysis. The risk of bias for individual studies was assessed using the Newcastle-Ottawa Scale. The quality of evidence across studies was assessed using the Office of Health Assessment and Translation (OHAT) approach.

Findings 144 studies were included in the systematic review, of which 19 were suitable for meta-analysis. Three meta-analyses were conducted for suicide outcomes: a 1°C increase in mean monthly temperature was associated with an increase in incidence of 1·5% (95% CI 0·8–2·2, p<0·001; n=1 563 109, seven effects pooled from three studies); a 1°C increase in mean daily temperature was associated with an increase in incidence of 1·7% (0·3–3·0, p=0·014; n=113 523, five effects pooled from five studies); and a 1°C increase in mean monthly temperature was associated with a risk ratio of 1·01 (95% CI 1·00–1·01, p<0·001; n=111 794, six effects pooled from three studies). Three meta-analyses were conducted for hospital attendance or admission for mental illness: heatwaves versus non-heatwave periods were associated with an increase in incidence of 9·7% (95% CI 7·6–11·9, p<0·001; n=362 086, three studies); the risk ratio at the 99th percentile of daily mean temperature compared with the 50th percentile was 1·02 (95% CI 1·01–1·03, p=0·006; n=532 296, three studies); and no significant association was found between a 10°C increase in daily mean temperature and hospital attendance. In a qualitative narrative synthesis, we found that ambient outdoor temperature (including absolute temperatures, temperature variability, and heatwaves) was positively associated with attempted and completed suicides (86 studies), hospital attendance or admission for mental illness (43 studies), and worse outcomes for community mental health and wellbeing (19 studies), but much of the evidence was of low certainty with high heterogeneity.

Interpretation Increased temperature and temperature variability could be associated with increased cases of suicide and suicidal behaviour, hospital attendance or admission for mental illness, and poor community health and wellbeing. Climate change is likely to increase temperature anomalies, variability, and heatwaves as well as average temperatures; as such, health system leaders and policy makers must be adequately prepared and should develop adaptation strategies. More high-quality, standardised research is required to improve our understanding of these effects.

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Introduction

Climate change is increasingly recognised as a health emergency, with rising temperatures and extreme weather events demonstrably disrupting health systems and societies.[1] Although a robust body of literature outlines the impact of climate-related disasters on mental health outcomes,[2,3] the implications of rising temperatures and more frequent heatwaves on mental health is insufficiently understood.[4] Evidence gaps regarding the mental health consequences of increased global temperature remain, alongside low awareness levels among mental health system professionals, public health leaders, and policy

Research in context

Evidence before this study

We conducted a scoping review of the field as part of a previously published briefing paper and narrative review on climate change and mental health; on Nov 15, 2019, we searched WebofScience, PsycINFO, Embase, PubMed, and Google Scholar using the terms "temperature", "heat", "heatwave", "warming", "season, "hot", "mental health", "mental illness", "wellbeing", "suicide", "psychosis", "anxiety", and "depression", with no date restrictions. We included only articles published in English. This search identified a gap in the literature for an up-to-date systematic review and meta-analysis on temperature and mental health. The association between ambient temperature and mental health has been widely researched with mixed results. Several previous systematic reviews have explored the impact of ambient temperature (including average temperatures, heatwaves, and temperature variation or anomalous temperatures) on mental health outcomes (including suicides, attempted suicides, hospitalisations for mental illness, and severity of symptoms). These reviews have highlighted that ambient temperature is associated with changes in mental health outcomes, and they have typically focused on suicide and hospital attendance, largely finding positive associations. These previous reviews have either limited their appraisal to studies suitable for a quantitative meta-analysis or only provided a qualitative synthesis, only included suicide as a mental health outcome, or solely focused on indoor temperature as the exposure. Individual studies suggest increased temperatures are associated with increased mental health risks and worse individual outcomes, but they exhibit variability in effect sizes and moderating factors. As such, the overall mental health risks of ambient outdoor temperature and reasons for variation in reported effect sizes have not been robustly interrogated. Before the current study, no comprehensive overview of the state and strength of evidence had been done both quantitatively and qualitatively. Additionally, no previous investigation has been done of the effects of temperature on a broader spectrum of mental health outcomes, such as emotional wellbeing across the population.

Added value of this study

We conducted both a quantitative and qualitative synthesis of the literature for a complete understanding of the current evidence base. We also examined a broad range of mental health outcomes, including self-reported mental health and wellbeing, that have not been included in previous reviews. Furthermore, we provide a novel mapping of the heterogeneous metrics and methods used in the literature to date and identify the key gaps in evidence. This mapping can be used to guide further standardised research needed across different global contexts.

Implications of all the available evidence

In our quantitative and qualitative syntheses, we found positive associations between increased absolute, variable (relative), and extreme temperatures and a range of mental health outcomes, including suicide, hospital attendance or admission for mental illness, and community mental health and wellbeing. Of note, many of the studies of absolute temperature metrics also controlled for season, month, or other temporal trends during the analysis. Therefore, these exposures might be interpreted as reflecting the impact of anomalous temperature (warm for that season or time of year). The results of our narrative synthesis and meta-analysis highlight the need for evidence-based policy to address and mitigate the mental health impacts of increased climatic temperatures, temperature anomalies, temperature variation, and extreme temperatures, particularly for communities and individuals most likely to be susceptible to the biological, societal, and economic stressors of high temperatures.

experts.[5] Theoretically, temperature could affect mental health via several mechanisms. These include physiological changes (such as alterations in blood flow or serotonin levels), cognitive changes (resulting from disrupted sleep at high temperatures and the effects of temperature on functional brain connectivity[6]), or societal changes (such as heightened aggression, stress resulting from reduced economic and agricultural outputs, and increased alcohol consumption).[6–8] Temperature could differentially affect the physiology of individuals with pre-existing mental illnesses, in part due to impairments in thermoregulation caused by psychiatric medications.[9]

The increasing burden of mental health disorders is a global challenge. A systematic review from 2022 showed that mental health disorders are consistently in the top ten leading causes of disease burden worldwide.[10] The total number of disability-adjusted life-years due to mental health disorders increased from 80·8 million in 1990 to 125·3 million in 2019.[10] To adequately build climate resilience into mental and public health systems, and to account for the true costs and benefits of climate mitigation and adaptation, it is vital to understand the impact of ambient outdoor temperature on mental health. This understanding must incorporate a broad range of mental health outcomes, and it should encompass non-clinical outcomes, such as community mental health and wellbeing, as well as clinically recognised mental illnesses (eg, depression and psychosis).

A 2019 meta-analysis observed an association between increasing ambient outdoor temperatures and completed suicide, although it did not evaluate other mental health outcomes, include all relevant articles, or provide a synthesis of studies that were not meta-analysed.[11] Another comprehensive systematic review showed associations between ambient temperature and suicide, and between ambient temperature and hospitalisations for

mental illness. However, this review did not include community mental health and wellbeing, nor a meta-analysis.[12] Since 2020, a further six systematic reviews have been published exploring associations between mental health and changes in ambient temperature.[13–18] Of these six, three focused exclusively on suicide as the outcome measure,[13–15] one used only indoor temperature as an exposure variable[16] and none incorporated a substantial breadth of mental health outcomes. All reviews were consistent in their findings that ambient temperature has an effect on suicide risk.

Our aim was to conduct a systematic review, incorporating a qualitative narrative synthesis and quantitative meta-analysis, of the current evidence regarding the effects of ambient outdoor temperature across a full spectrum of mental health outcomes, including clinically relevant outcomes (such as suicide or symptoms of mental illness) and non-clinical outcome variables (such as community wellbeing).

Methods

Search strategy and selection criteria

We conducted a systematic review and meta-analysis of the evidence regarding associations between ambient outdoor temperature and changes in mental health outcomes. The initial searches, data extraction, and analysis were conducted on March 20, 2020. An updated search and analysis occurred on April 6, 2022.

The search strategy was developed using the Population, Exposure, Comparator, and Outcomes (PECO) approach to question formulation[19] and was designed to ensure all papers relating to mental health outcomes and their association with ambient outdoor temperature were identified. Mental health is a broad term incorporating a wide range of clinically defined conditions, as well as more broadly defined and multi-faceted manifestations, such as wellbeing.[20] Because this systematic review relied on using other researchers' definitions, the search strategy was kept deliberately broad to account for both clinically focused mental health definitions and outcomes (eg, suicide and recognised mental illnesses), and non-clinical mental health and wellbeing across the population (eg, positive affect, depressive symptoms in the community).

We searched WebOfScience, Embase, PsychINFO, and PubMed for articles published from database origin to April 7, 2022. Search terms were selected after a review of titles and keywords in known eligible literature. The full search strategy and explosion terms developed in line with the PECO approach are available in the appendix (pp 2–3). Reference lists of review articles and identified studies were also scanned for additional relevant studies. Studies were included within the systematic review if they met the following criteria: epidemiological, observational studies of real-world responses to ambient outdoor temperature; studies of human beings of all ages; studies that had mental health as a documented outcome (including but not limited to mental illness, suicide, psychosis, anxiety, depression, or wellbeing). The following studies were excluded: experimental studies of the effects of manipulated or controlled temperature; studies using indoor temperature, body temperature, or subjective temperature as an intervention or exposure variable; animal studies; studies exploring neurodevelopmental, neurodegenerative, organic, or behavioural disorders; studies with only physical health outcomes.

The study team made a pragmatic decision to focus on psychiatric conditions and mental health outcomes. Given the debate regarding whether conditions such as behavioural and developmental disorders (eg, autism) should be classified as mental health disorders at all, we elected to exclude these papers. The exclusion criteria were designed to improve the feasibility of this review, and to increase the likelihood of presenting a cohesive argument regarding the impact of ambient outdoor temperature on mental health.

The literature search and article selection processes were conducted in duplicate and independently by RT and LFR to reduce bias. Articles were initially included based on title screening. After removal of duplicates, abstracts were assessed against the inclusion and exclusion criteria. If the abstract lacked sufficient detail to assess alignment with eligibility criteria, full-text screening was conducted. All studies were screened and selected for eligibility by two independent reviewers (RT and LFR), with discrepancies resolved by a third reviewer (ELL). If an article or effect size was not available, authors were contacted for this information.

The study protocol was registered on the PROSPERO database (CRD42022324885).

Data analysis

Once selected for inclusion, the full texts of all articles were reviewed. Reviewers (RT and LFR) extracted the following fields: authors, year, population outcomes investigated, outcome measure and data source, location and time period of study, study design and analysis, temperature measure and data source, variables controlled for, results, and effect. These were verified for accuracy by another reviewer (RT, LFR, or ELL). Any missing fields were marked as unknown.

The quality of individual studies was assessed by two reviewers (RT and LFR) using a modified version of the Newcastle-Ottawa Scale.[21] Selection of the appropriate subset of relevant scale items for each study design gave maximum scores of 8–12, depending on the sources of potential bias present in each design. Scores were standardised to create a final quality score out of 8 for each article. Studies were classified as having a high risk of bias if the score was less than or equal to 6, a moderate risk of bias if the score was greater than 6 and less than or equal to 7, and a low risk of bias if the score was greater than 7, in accordance with previous literature.[22,23] Two points could be

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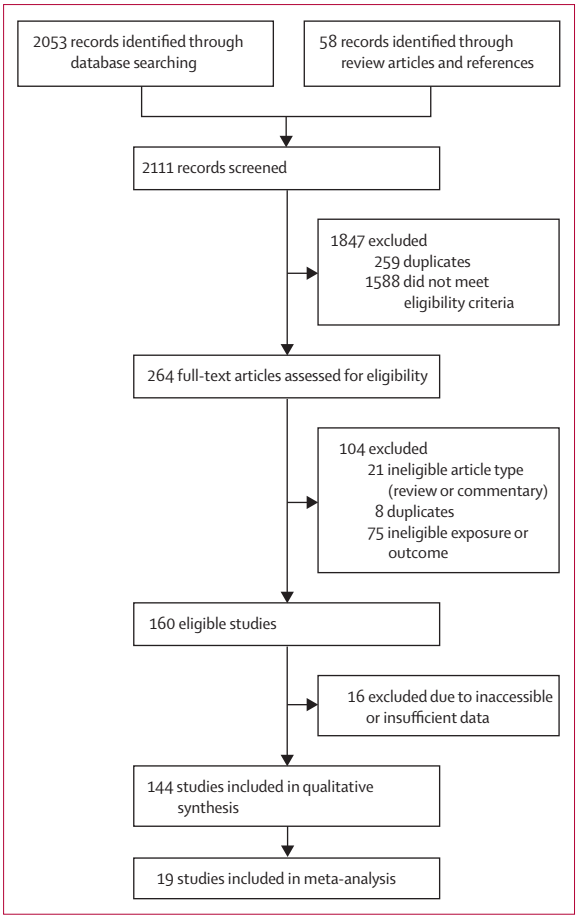

Figure 1: **Study selection**

allocated for controlling of appropriate confounders, with one of these points available only if effects were adjusted for a time variable or time-trend that was likely to co-vary with mental health outcomes. We planned to assess publication bias using funnel plots and Egger's regression test.

Ambient temperature exposures and identified mental health outcomes were categorised, synthesised, and reviewed for any evidence of associations quantitatively and qualitatively. The overall certainty of collective evidence across associations (for each outcome-exposure category) was subsequently assessed by applying the US National Toxicology Program Office of Health Assessment and Translation (OHAT) approach.[24] The Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) framework[25] is the gold-standard evaluation tool for evidence certainty in medicine, but it is more suited to experimental designs, such as randomised controlled trials, and penalises observational design characteristics. The OHAT approach is designed to apply GRADE to environmental and occupational health by basing initial ratings on design considerations specific to this field;[26] therefore it is the optimal choice for systematically reviewing this literature. Associations (between each combination of exposure and outcome assessed) were given initial certainty ratings based on the number of the following design characteristics that were met (moderate rating if all three were met, low rating if two were met, very low rating if one was met): comparisons were made between participants at various exposure levels; data were individual-level; and it was a longitudinal study (the fourth design characteristic in the OHAT approach, controlled exposure, was not applicable to this literature). In this approach, association certainty could then be downgraded based on risk of bias concerns (based on Newcastle-Ottawa Scale rating), inconsistency (disagreement or apparently contradictory findings within or between studies), imprecision (wide confidence intervals or small number of studies), or indirectness (if the methods were not directly measuring the exposures or outcomes of interest or used heterogeneous metrics reflecting differing outcomes). Association certainty could be upgraded if associations in the literature showed a dose-response relationship, exhibited large effect sizes, or if any apparent biases were likely to reduce (not increase) the observed effect. After the initial rating and possible downgrading and upgrading, associations received a final rating (high, moderate, low, or very low) reflecting our confidence in the body of evidence presented by the literature and the overall conclusions that could be drawn from it.

The mental health outcomes and exposure metrics reported within selected studies were tabulated, reviewed for similarities, and allocated into outcome groups and exposure categories. A narrative synthesis was conducted for each outcome group and papers were further stratified within these syntheses according to the temperature exposure category they evaluated. Studies were summarised with respect to their location, quality, and findings.

Articles were deemed appropriate for meta-analysis if three or more separate studies reported the same or equivalent effect statistics, and if they had an equivalent exposure, outcome, and metrics, such that effects could be meaningfully and interpretably pooled. Statistics with the same meaning were converted to the same scale (eg, incidence expressed as per 100 000 population could be converted to a percentage of the population). Some temperature metrics were also converted from °F to °C. If an article reported several estimates derived using different models, but these applied to the same population or sample, we included the estimate from the model including the most covariates in the meta-analysis. The DerSimonian and Laird inverse-variance random-effects model was estimated using Stata 13. $p<0·05$ was considered to indicate statistical significance.

Role of the funding source

There was no funding source for this study.

Results

Our search identified 2053 articles, with an additional 58 records identified via review articles and reference lists. 264 full-text articles were assessed for eligibility, of which 144 were included in the qualitative narrative synthesis (figure 1). The included studies were categorised into three outcome groups: suicide; hospital attendance or admission for mental illness; and community mental health and wellbeing. Given the broad range of definitions and variables for ambient outdoor temperature, the studies were also categorised according to the exposure variable metric: absolute temperatures (eg, mean, minimum, or maximum); temperature variability, referring to metrics of quantified relative temperature (eg, inter-day or intra-day variation, departure from average); and heatwaves and extreme temperatures (appendix p 4). These categories contain a range of different metrics (eg, mean and minimum under absolute temperature), which the categorisation is not intended to conflate; they provided a pragmatic starting point for synthesising a large amount of heterogeneous literature. Some papers contained data pertinent to more than one outcome or exposure and were evaluated in more than one category.

The distribution of articles across geographies, study variables, and methods is described in the appendix (pp 4–19). Due to large heterogeneity in methods, meta-analysis was possible for only 19 studies. This also meant the number of studies methodologically similar enough to pool their effects quantitatively was insufficient for funnel plots or regression-based analyses. The full risk-of-bias assessment per study is presented in the appendix (pp 20–33). Texts excluded after full-text screening, with reasons for exclusion, are shown in the appendix (pp 34–37). Collective evidence certainty assessments by exposure-outcome categories (ie, for each association reported) are also presented in the appendix (p 38).

Associations between suicide and temperature were evaluated in three meta-analyses. First, in a meta-analysis of suicide incidence and mean monthly temperature (figure 2A; seven effects pooled from three studies,[27–29] n=1 563 109), we found an increase in incidence of 1·5% per 1°C increase in temperature (95% CI 0·8–2·2, p<0·001), although heterogeneity was high (I^2 99·9%, p<0·001). Second, in a meta-analysis of suicide incidence and mean daily temperature (figure 2B; five effects pooled from five studies,[30–34] n=113 523), we found an increase in incidence of 1·7% per 1°C increase (0·3–3·0, p=0·014; I^2 99·7%, p<0·001). In a meta-analysis of suicide risk and a 1°C increase in mean monthly temperature (figure 2C; six effects pooled from three studies,[27,35,36] n=111 794), we found a risk ratio of 1·01 (95% CI 1·00–1·01, p<0·001; I^2 60·7%, p=0·026).

86 studies investigated suicide (completed and attempted) and were included in the narrative synthesis (appendix pp 39–67). The quality of evidence for associations between completed suicides and absolute temperatures (72 studies), assessed using the OHAT approach, was moderate with, in most cases, an increased incidence and risk of suicide at higher mean, maximum, and minimum temperatures. These studies were categorised as absolute temperature because the exposure metrics applied by authors were absolute values (eg, mean or minimum), but these studies often adjusted for season, month, or time trend when reporting positive significant results. As such, they might be more sensibly interpreted as suggesting that anomalous (eg, unseasonably high) temperatures are associated with suicides as opposed to higher absolute temperatures (eg, at tropical locations or during the hottest months of the year). Consistent with this suggestion, the mean temperature for the day of the year and average temperature for each US district were

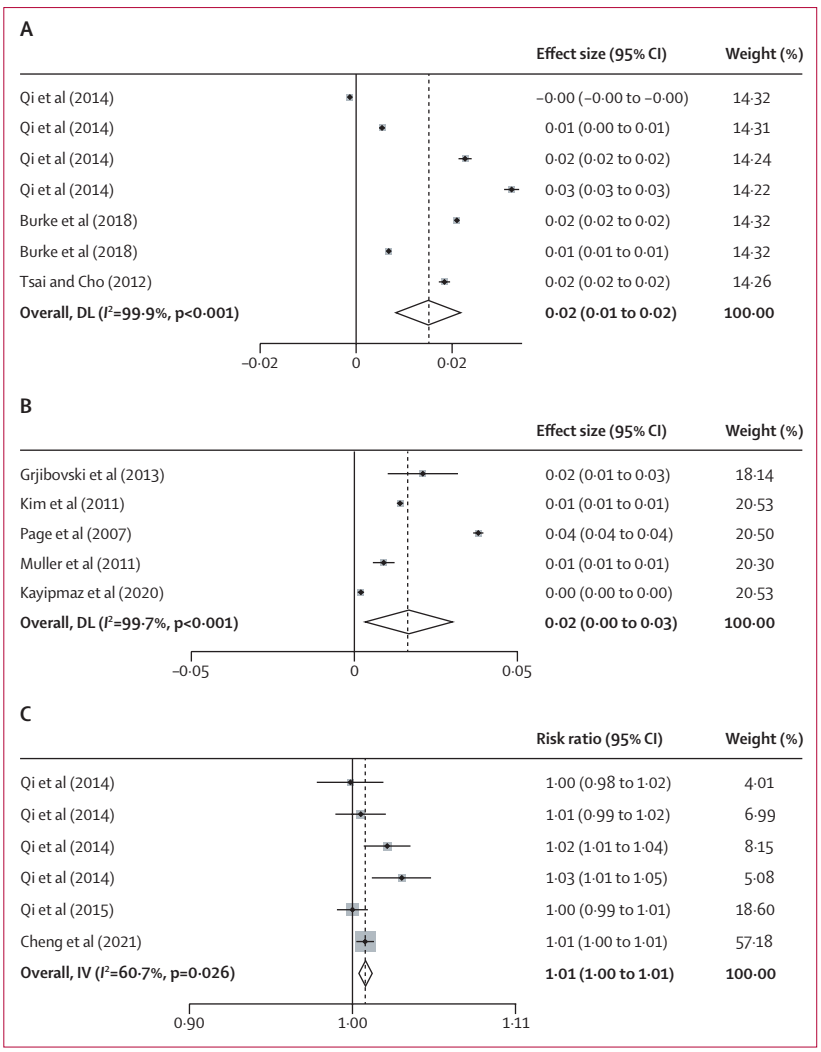

Figure 2: **Forest plot of meta-analysed associations between temperature and suicide outcomes**
(A) Increased suicide incidence per 1°C increase in mean monthly temperature. (B) Increased suicide incidence per 1°C increase in mean daily temperature. (C) Increased risk ratio for suicide per 1°C increase in mean monthly temperature. DL=DerSimonian and Laird approach. IV=inverse variance.

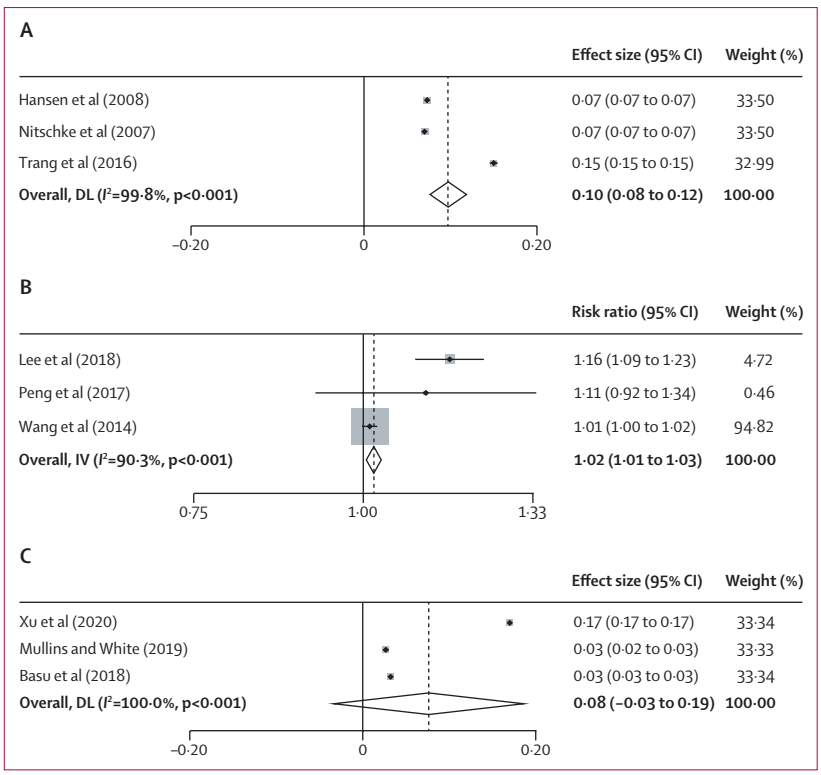

Figure 3: **Forest plot of meta-analysed associations between temperature and hospital attendance or admission for mental illness**

(A) Incidence of hospital attendance or admission for mental illness during a heatwave (daily maximum temperature of ≥35°C for ≥3 days) compared with a non-heatwave period. (B) Pooled risk ratio of admission to hospital for mental illness when daily mean temperature exceeded the 99th percentile compared with the 50th percentile. (C) Pooled increased incidence of hospital attendance or admission for mental illness per 10°C increase in daily mean temperature. DL=DerSimonian and Laird approach. IV=inverse variance.

not consistently associated with completed suicides in one study.[37] Even within the same categories of exposure and outcome, many heterogeneous results were reported. For example, Burke and colleagues[28] reported a significant increase in monthly suicides per 1°C increase in mean monthly temperature of 0·68% in the USA and of 2·1% in Mexico, but Kurokouchi and colleagues[38] did not find consistent associations between monthly suicides and mean monthly temperature in the USA and Japan, demonstrating how similar data analysed differently (different covariates and statistical analyses) might generate a different result. Methodological heterogeneity precludes us from an in-depth or quantitative comparison of the studies within this narrative synthesis to determine if differences are real world (eg, context-dependent) or methodological in origin. Inconsistencies in study findings or imprecision (too few studies) meant that the evidence for temperature variation and completed suicides (17 studies), heatwaves and completed suicides (seven studies), absolute temperatures and suicidal behaviours (16 studies), temperature variation and suicidal behaviour (one study) and heatwaves and suicidal behaviour (one study) were all assessed as low certainty. These studies also tended towards positive associations between increased temperature and suicide but presented large heterogeneities in methods and results.

Several studies examining the effect of temperature variation and heatwaves on hospital attendance or admission for mental illness contained effects that were suitable for meta-analysis. A meta-analysis of three pooled effects from three studies[39–41] (n=362 086) indicated that a heatwave, defined as daily maximum temperatures of at least 35°C for at least 3 days, corresponded to a 9·7% higher incidence of hospital attendance or admission for mental illness than non-heatwave periods (95% CI 7·6–11·9, p<0·001), with high heterogeneity (I^2 99·8%, p<0·001; figure 3A). Three studies[42–44] (n=532 296) compared the risk of hospital attendance or admission when daily mean temperatures were at or above the 99th percentile to when the mean temperatures were at the 50th percentile (figure 3B). The pooled risk ratio was 1·02 (95% CI 1·01–1·03, p=0·006), with high heterogeneity (I^2 90·3%, p<0·001). Finally, effects from three studies[45–47] (n=4 129 333; figure 3C) were pooled to estimate the change in incidence of admissions per 10°C increase in daily mean temperature, corresponding to a non-significant increase.

Hospital attendance or admission for mental illness was reported in 43 studies (appendix pp 67–81). Of the three mental health outcome categories, the hospitalisation literature was of the highest quality. The certainty of evidence, assessed by the OHAT approach, was moderate for temperature variation (nine studies) and heatwave (ten studies), and low for absolute temperature metrics (39 studies) due to variable effect sizes, resulting in wide confidence intervals in meta-analysis (figure 3). Nine (100%) of the temperature variation studies, nine (90%) of the heatwave studies, and 35 (90%) of the absolute temperature metric studies reported significant positive associations between higher temperatures and hospital attendance or admission for mental disorders. 26 (60%) of 43 studies evaluated any psychiatric disorder and 17 (40%) evaluated specific conditions or behaviours. Similar to the suicide literature, many studies using absolute temperature metrics, including those contributing to meta-analysis, adjusted for season or other temporal variables. Methodological differences were apparent; these might have contributed to heterogeneity in effect sizes, which was the reason why evidence certainty was downgraded to low for associations between absolute temperatures and hospital attendance or admission. For example, two studies[48,49] evaluated psychiatric admissions in relation to daily mean temperature. Of these, one[48] reported a strong and significant linear association yet the other[49] reported no significant association, highlighting a potential effect of different statistical approaches to modelling and covariates.

A third group of studies evaluated ambient outdoor temperature and community mental health and wellbeing outcomes (19 studies, appendix pp 81–94). These studies had the most heterogeneous methodology and outcome metrics, precluding meta-analysis, and were analysed qualitatively. The assessment of certainty by GRADE was low for absolute temperatures (18 studies) due to indirectness (disparate outcomes measured with a range of metrics) and for temperature variation (five studies) due to risk of bias concerns. Heatwaves were not studied. Most studies (13, 68%) measured mental health and wellbeing using surveys, with variables such as mood, positive and negative affect, wellbeing, psychological distress, and depression symptoms, and inconsistency in survey instruments across studies.[47,50–61] 16 (84%) studies[28,47,50–52,55–65] reported a significant association between at least one temperature metric and at least one mental health or wellbeing metric. 14 (74%) studies[28,47,50–52,55,56,59–65] showed that higher temperatures were typically associated with worse outcomes. One study found improved wellness scores with "comfortable weather hours" in summer,[58] and one found improved mood for time spent outside in spring (in "pleasant" temperatures), but worsened mood for time spent outside in summer.[57] Three studies (17%) did not find a significant association between temperature and mental health or wellbeing.[53,54,66]

Discussion

This systematic qualitative narrative review and meta-analysis found supportive evidence for associations between suicide and suicidal behaviours with increasing absolute temperatures, variable temperatures, and heatwaves; hospital attendance or admission for mental illness with absolute temperatures, temperature variability, and heatwaves; and between community mental health and wellbeing with absolute temperatures and temperature variability. However, due to heterogeneities in methodology and variable effect sizes, most of this collective evidence was of low certainty.

We imposed umbrella categories of temperature metrics to make sense of the literature, but each category contained a wide range of metrics and definitions. For example, the absolute temperature category included mean, maximum, and minimum temperatures. The temperature variability category contained relative values explicitly calculated to serve as the exposure metric, such as diurnal temperature, inter-day range, or deviation from average for a particular place or time. The heatwaves category reflected exposure to extreme temperatures that had been defined as a heatwave event by the authors of included studies. However, many of the significant studies using absolute temperature metrics also controlled for season, month, or other time-trends; although this approach adjusts for potential time-varying trends in mental health, it also means the effect of absolute temperature in these cases can be interpreted in part as the impact of anomalous temperatures (eg, by controlling for the contribution of the time of year to temperature effects). Effectively, this means that results should largely be interpreted as higher temperatures, relative to the norm for that location and time of year, worsening mental health outcomes, although the methodologies used across the literature still preclude strong concluding statements. This finding is consistent with the weaker evidence of mental health effects observed within the temperature variability category for studies of geographical variation in temperature (hotter *vs* cooler places) compared with studies of temperature variation within one place (eg, diurnal range).

Overall, the evidence synthesised here indicates an effect of rising, variable, and extremely high temperatures on mental health outcomes. Our results are consistent with previous reviews and meta-analyses.[11–18] Although trends can be observed, the variability in reported effect sizes across outcome and exposure categories could be due to modulation of the impact of temperature on mental health by contextual factors that were inconsistently accounted for in the literature (eg, demographic, temporal, and other weather variables), and lag effects, whereby temperature exposure over different time windows affects mental health outcomes to varying degrees. Gender and age often acted as moderating variables in whether an effect was present or absent. Furthermore, although the evidence for suicide and hospital attendance or admission indicated that relatively hotter temperatures are detrimental, so-called comfortable weather and sunshine hours were reported to be beneficial for community mental health and wellbeing. An inverted U-shaped relationship might exist between heat and general mental health or wellbeing, whereby increasing temperature is beneficial up to a point before becoming detrimental. Other factors, such as humidity, precipitation, and sunshine could also impact psychological state and its association with temperature. Taken together, the evidence suggests that the relationships between temperature and mental health outcomes are context-dependent and non-linear, with the temperature relative to the local average more important than its absolute. Hence, local data should be used to inform local policy responses. Associations are also likely to vary by outcome. Across both the narrative synthesis and meta-analyses, a large amount of evidence was supportive of these relationships, but more high-quality research is required to improve confidence in the conclusion that ambient outdoor temperature affects suicide risk, and to identify when and where these associations are present.

This study provides a comprehensive synthesis of current evidence for the effect of temperature on mental health. Strengths include our use of a highly systematic, rigorous, and replicable approach across the entire review (including evidence identification, documentation,

evaluating risk of bias, assessing evidence certainty, and the integration of qualitative and quantitative evidence). We included a broad range of mental health outcomes not included in previous reviews, such as wellbeing. We mapped the metrics and methods used to date to identify key gaps in the evidence, exposing large heterogeneities, as well as unevenness in geographical coverage, which the field must address.

However, several limitations should be considered when interpreting our findings, some of which are limitations of the literature rather than our approach to reviewing it. First, only a small proportion of the literature was sufficiently comparable to warrant inclusion in meta-analysis, although these studies were of higher quality than the literature overall. Second, heterogeneity (I^2) was high for effect estimates in all meta-analyses. Third, insufficient data were available to account for the potential impact of other interacting weather and demographic variables on the effect sizes in our meta-analysis, to conduct subgroup analyses, or to provide a synthesis by geographic region. Fourth, this systematic review is inherently limited by the variability of language and definitions used by researchers when investigating the effects of ambient outdoor temperature on mental health. Our approach to categorisation of temperature metrics informed the conclusions that could be drawn, but it is not the only valid approach. The description of mental health in the literature also varied considerably, including definitions of illness, diagnoses, and symptoms. As such, we kept the search terms deliberately broad, and did not use specific International Classification of Diseases codes within the search strategy to minimise the risk of missing studies due to unreliable indexing. Finally, although our review comprehensively summarises the literature to date for the three mental health outcomes as defined during the review and synthesis process, we did not examine increased susceptibility to physical morbidities and mortality for those with pre-existing mental illness. Individuals with mental disorders are known to have increased susceptibility to physical illnesses (and vice versa) and appear to be a susceptible group to physical effects of heat.[67] This association presents a confounding risk to the mental health outcomes literature because it could be that help-seeking for the physical effects of heat increase the detection, rather than the actual incidence, of mental health emergencies. Future research should attempt to disentangle the two.

The literature was limited by numerous heterogeneities in both research metrics and methods, which sometimes precluded study comparison and estimate pooling. The quality of collective evidence for the reviewed associations was often downgraded due to inconsistency between study findings, made likely by such heterogeneities. Standardisation across this field is needed to generate more easily comparable results amenable to synthesis. We developed a summary table of metrics, methods, and frequency of use across the literature to date, as a resource for the field to guide metric and method selection and encourage quality and consistency (appendix p 4). The field would benefit and comparisons and meta-analysis would be easier if a smaller range of temperature metrics were used, although we acknowledge the widespread interest in investigating the impact of different variables. We suggest to this end that researchers standardise their approaches with a focus on daily mean, the departure of the daily mean from average for that time of year and place, and a consistent definition of heatwaves.

We identified some key gaps in the evidence base that should be considered further. First, the effects of the rate of temperature change and time lags from exposure to outcome require further analysis, because some of the synthesised literature showed significant effects of temperature (eg, an anomalously hot day) at certain time lags, timescales, or durations. Second, further investigation is needed of the mechanisms underlying temperature effects, including the biological and contextual drivers. Although some evidence exists for the effect of temperature on factors relevant to mental health outcomes, such as sleep disruption, increased conflict, cognitive changes, or the impairment of thermoregulation by psychoactive medication, many of the biological and social pathways by which temperature affects mental health remain insufficiently clear or merely hypothesised.[6] Third, interventions designed to prevent and respond to the effects of rising temperatures on mental health need to be identified and evaluated, because few interventions have been designed, tested, and implemented to date. Fourth, more studies of associations between temperature and mental health need to be done in low-income and middle-income countries. Although many of these countries or contexts are particularly affected by increased temperatures, low-resource settings and entire regions, such as South America, have received almost no attention in the literature. Fifth, the effects of demographic and other contextual variables remain unclear, including socioeconomic conditions and urbanisation. The use of meta-regression to account for covariates, such as geographic region, might help to distinguish factors that affect only certain regions or groups. Little consideration has also been given to the effects of indoor temperatures and adaptations such as insulation and air conditioning on mental health outcomes. Finally, evidence on the effects of temperature on general mental health and wellbeing, in addition to acute outcomes, is scarce.

The evidence in this review was stronger for the effects of extremely high and variable temperatures over absolute temperatures. As such, an increase in average absolute temperatures resulting from climate change might not necessarily increase mental health issues, because people might adapt over time, meaning that higher temperatures could become normal and not be experienced as anomalous or extreme. However, climate change is also likely to lead to an increase in heatwaves, temperature

variability, and anomalies (relative to contemporaneous averages[68–70]). Therefore, the findings of this study suggest that the effects of climate change on temperature variables (particularly greater extremes and variability) are still likely to have a negative impact on some of the three categories of mental health outcomes explored within this review: suicide, hospital attendance or admission for mental illness, and community mental health and wellbeing. Consequently, without action to mitigate climate change and build resilience in infrastructures, health systems, and communities, current and future increases in ambient outdoor temperatures are likely to further increase the incidence of negative mental health outcomes. Evidence-based action is needed in policy and practice to mitigate and prepare for these effects. Such action is the only way to adequately support people and prevent worsening mental health outcomes both now and with the ongoing effects of climate change, especially for those who are already susceptible due to their psychological, social, and economic conditions.

Contributors

ELL and RT are joint first authors and made equal contributions to this report. ELL conceived and project managed the study and ELL, HA, and RT designed the study methods. RT and LFR did the systematic review of the literature. ELL, LFR and RT did the qualitative synthesis and HA did the meta-analysis. ELL and RT drafted the initial manuscript. KG revised the manuscript following review. All authors made manuscript revisions before submission of the approved final version of the report. RT and HA accessed and verified the data used in the study, and all authors had full access to all data included in this study and accept responsibility for its publication.

Declaration of interests

We declare no competing interests.

Data sharing

All meta-analyses reported in this study are available on request to the corresponding author, including data used for analyses and analytic code. Data extracted from included studies are available in the main report and in the appendix. Further information extracted for management of the review and meta-analysis is available from the corresponding author on request.

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