Hot instantaneous temperature and affect: Meaningful activities as a buffer for older adults with low socioeconomic status

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Abstract

Background and Objectives: Extremely hot temperature affects psychological well-being negatively, especially for older adults with lower socioeconomic status (SES). The objectives of this study are to examine: (1) the impact of hot instantaneous temperature on older adults' emotional well-being; and (2) whether meaningful engagement could reduce the above impact, particularly for those of lower SES.

Research Design and Methods: We conducted a quantitative time sampling study during hot-weather months (May–September) in 2021 and 2022. The sample comprises 344 participants aged 60 years or above (M_{age} = 67.15, SD_{age} = 5.26) living in urban areas of Hong Kong, where hot days (daily maximum temperature >= 33℃) accounted for 23% of the study days. Participants reported positive and negative affect, and engagement in meaningful activities, three times a day over a 10-day period, and wore sensors that tracked the instantaneous temperature of their immediate environment. Multilevel modeling was employed to examine the impacts on affect from temperature, SES, and meaningful activity engagement.

Results: Hotter instantaneous temperature predicted greater momentary negative affect and less positive affect immediately afterwards. Meaningful engagement significantly buffered against the affective impacts of hotter temperature, and this buffering effect was more salient among older adults of lower SES.

Discussion and implications: This study highlights the role of meaningful engagement in reducing the impact of hotter instantaneous temperature on older adults' emotional well-being, particularly for those of lower SES. Meaningful activity engagement may be capitalized on, as a strategy, to reduce climate-related social inequality.

Translational Significance

Hot temperatures have been shown to harm older adults' well-being, particularly those with lower socioeconomic status (SES). We found in Hong Kong – one of the hottest cities with the highest income inequality in the world – that meaningful activity engagement could buffer against the negative impact of hot instantaneous temperature on older adults' emotional well-being. This buffer worked even better for those with lower SES. Findings suggest that personal agency should not be ignored in fighting hot weather. As meaningful engagement is less resource-dependent, it can complement existing macro-level strategies (e.g., urban design) to help older adults cope with global warming.

Keywords: Extremely hot weather, Psychological well-being, Daily affect, Meaningfulness, Socioeconomic status

1 Introduction

Amid global warming, extremely hot weather is expected to become more intense and long-lasting every decade. Increasing occurrences of extremely hot temperatures boost heat-related morbidity and mortality (Deschênes & Greenstone, 2011; Gasparrini et al., 2015), adversely affecting people's physical and psychological well-being (Pailler & Tsaneva, 2018). An important contributor to psychological health and life functioning is emotional well-being, characterized by experiencing more positive affect and less negative affect. People with better emotional well-being have lower risk of mental and behavioral illnesses (Hansen et al., 2009). For older adults, specifically, better emotional well-being is associated with fewer distress and depressive symptoms, and better physical and mental health (Hu & Gruber, 2008). However, hotter weather is associated with decreased emotional well-being. Evidence was found that people living in hotter regions in the world have lower levels of happiness (Rehdanz & Maddison, 2005), and people show worse daily moods (Denissen et al., 2008) and diminished life satisfaction (Connolly, 2013) in hotter days. Older adults living in hot and densely populated areas are especially vulnerable to the impacts of extremely hot weather. Tropical and sub-tropical regions experience more heatwaves than the rest of the world (Guo et al., 2018). Urban areas, especially high-density cities, suffer from greater impacts of heat waves because the urban heat island (UHI) effect aggregates more heat (Li & Bou-Zeid, 2013). In view of these, this study examined the impact of hot instantaneous temperature on the emotional well-being of older adults and what can be done to reduce the impact, in Hong Kong – a high-density urban city in the tropical region that has the world's highest intracity income inequalities and one of the world's highest average increases in urban ambient temperature during the past century (United Nations Development Programme, 2022).

Due to declining physical health and thermoregulatory function, older adults are more susceptible to heat-related symptoms versus younger adults (e.g., heat syncope, heat cramps; Teyton et al., 2022). Research found that increased ambient temperature in Hong Kong from 2000 to 2016 was associated with higher risk of acute psychiatric disorder episodes in adults aged 65 years and older (Qiu et al., 2022). Moreover, temperature can affect older adults' emotional well-being indirectly by restricting mobility. One study showed that mobility and social engagement were more negatively impacted by extreme weather among older than younger adults (Clarke et al., 2015), and this can result in loneliness and diminished emotional well-being in older age. Older adults of lower socioeconomic status (SES) may be even more impacted by the temperature changes in Hong Kong from 1998 to 2006 (Chan et al., 2012) as they usually have poor living conditions. Larger family sizes and congested indoor living spaces make it harder to ventilate during hot days (Joseph et al., 2016). Due to resource constraints, it is more challenging for lower-SES families to maintain a comfortable household temperature (Bagley et al., 2015). Though evidence was found on a long-term level that older adults, particularly those of lower SES, are at increased risk of negative emotional well-being impacts from extremely hot weather, whether hot instantaneous temperature of their immediate environment will affect their day-to-day well-being is under-researched.

Given the well-being risks of hot temperature, investigation of coping methods against hot weather, especially those that are accessible for individuals with age-related and socioeconomic vulnerabilities, is urgently needed. Interventions suggested by previous studies, such as those related to urban construction and building design, have mainly been on the macro level (Gronlund et al., 2018). Given that macro-level interventions take time to be implemented on a large scale, adaptive methods on the personal level are needed to inform

what vulnerable people (e.g., older adults of lower SES) can do immediately to maintain high levels of well-being in hot temperature.

Meaningful engagement and its psychological benefits

We propose that meaningful engagement, or engagement in personally meaningful activities, can buffer against the negative impacts of hot temperature on older adults' emotional well-being. People who engage in personally meaningful activities have a greater sense of well-being and meaning in life (Hooker et al., 2020; Eakman et al., 2010). For older adults, meaningful engagement is a critical component for successful aging as it helps them to maintain or improve their physical, social, and psychological functioning (Carlson et al., 2015; Fried et al., 2004).

Why is engaging in meaningful activities so important and beneficial to older adults? The theoretical foundations can be rooted in flow theory (Csikszentmihalyi, 1990), self-determination theory (SDT; Deci & Ryan, 2000), and socioemotional selectivity theory (SST; Cartensen et al., 2003). Research on flow theory provides evidence of the beneficial effects of engagement. With intense concentration and full engagement in an activity, one experiences flow. Several studies have shown that a sense of flow positively correlates with psychological resilience (Zubair & Kamal, 2015), psychological well-being (Bryce & Haworth, 2002), and life satisfaction (Peterson et al., 2005).

Meaning is another crucial factor that determines whether an activity is salutary to personal well-being. SDT suggests that people tend to find meaning in activities that satisfy the basic psychological needs of autonomy, relatedness, and competence (Deci & Ryan, 2000). When basic needs are satisfied, people achieve their optimal state of functioning and therefore, their well-being (Steger et al., 2008). Meaningful activities could be especially important for older adults' emotional well-being. According to SST, with limited future time,

older adults have an increased tendency to pursue emotionally meaningful goals (Cartensen et al., 2003). Research has found that meaningful activities such as productive and prosocial activities are positively associated with older adults' well-being through fulfilling emotionally meaningful goals (Okun et al., 2013; Vozikaki et al., 2017). In addition, any activity that is personally valued can contribute to a person's subjective sense of vitality and life satisfaction (Eakman et al., 2010; Hooker et al., 2020).

Vital engagement theory, as an extension of flow theory, emphasizes on the interplay between meaningfulness and engagement (Nakamura & Csikzentmihalyi, 2003). If the process is not enjoyable, the perceived significance of an activity is insufficient to maximize the benefits that it can provide to an individual. Likewise, merely engaging in an activity but not finding it meaningful is insufficient in providing long-term benefit to emotional well-being. Empirical studies have confirmed that for older adults, engaging in any activity is better than nothing (Cohen-Mansfield et al., 2010), but activities that are personally meaningful are more strongly associated with self-rated health and life satisfaction (Eakman et al., 2010).

Meaningful engagement buffers against the negative psychological impact of hot temperature

Although meaningful engagement has not been studied as a protective factor against the emotional well-being impacts of hot temperature, its buffering effect has been found when coping with many stressful events, such as traumatic injury, depression, and work stress (Britt & Bliese, 2003; Hutchinson et al., 2003; Maruta et al., 2020). An explanation for this buffering effect could be mental distraction (Hutchinson et al., 2003): When engaging in meaningful activities, individuals focus on what they are doing but not on stressful circumstances, such as difficult weather conditions. Moreover, consistent meaningful

engagement contributes to a healthier lifestyle that correlates with higher health-related quality of life among older adults (Eakman et al., 2010), which may in turn equip them with greater resilience to the adverse impacts of hot temperature on emotional well-being.

We expect the proposed buffering effect of engaging in meaningful activities on the emotional well-being impact of hot temperature will be stronger in older adults with lower SES. Given the vulnerability of people with lower (vs. higher) SES to the adverse effects of extreme weather (Chan et al., 2012), they should have higher coping needs and may hence derive more benefits from coping strategies. Although no previous research identified differing buffering effects of meaningful engagement across different SES contexts, other psychological variables, such as social connections, have shown such differences (Levine, 2017). People with higher SES benefit less from social connections because they are more likely to have enough resources to solve their own problems (Kraus et al., 2012). Similarly, people with higher SES have more resources to deal with hot temperatures, and to maintain their immediate temperature within a comfortable range (e.g., air-conditioning). People with lower SES, in contrast, have greater exposure to heat because air-conditioning is less affordable for them (Graff Zivin & Neidell, 2014). Hence, the buffering effect of meaningful engagement on the adverse emotional well-being consequences of hot temperature may be more helpful to lower-SES individuals.

2 Current study

We conducted this study to examine the impact of hot instantaneous temperature of participants' immediate environment on older adults' emotional well-being and to test the potential mitigating effect of meaningful engagement. This examination of potential buffers will help narrow the gap between older adults of different social classes amid global warming.

Using a time-sampling design with older adults, we plan to test the following hypotheses:

H1: Hotter instantaneous temperature is associated with worse concurrent emotional well-being (operationalized as more negative affect and less positive affect).

H2: Greater meaningful engagement is associated with better concurrent well-being (more positive affect and less negative affect).

H3: Meaningful engagement buffers against the negative effect of hot instantaneous temperature on emotional well-being.

H4: The buffering effect of meaningful engagement is stronger among participants of lower SES as compared to those of higher SES.

2.1 Method

2.1.1 Participants and weather conditions

The study was approved by the Survey and Behavioural Research Ethics Committee of the corresponding author's institution. The sample size of this study was not predetermined. We recruited participants to our full capacity (based on device and interviewer availability) during the hottest period in Hong Kong (May to October), in two waves: 2021 and 2022. Amid varying periods of restrictions associated with the COVID-19 pandemic, we manage to recruit 188 participants in 2021 and 156 in 2022. Participants who completed less than 20 out of 30 time-sampling surveys and/or those who did not provide instantaneous temperature data due to technical issues were excluded from data analysis. The final usable sample sizes were 171 (age range = 60-89) in 2021 and 150 (age range = 60-85) in 2022. Participant demographics are shown in Table 1. The weather conditions for the two waves were comparable. The number of very hot days (i.e., daily maximum temperature >= 33.0℃) was 54 in 2021 and 52 in 2022 (Hong Kong Observatory, 2022). The range of

instantaneous temperatures recorded was 17.05–38.94℃ in 2021 and 19.21–37.27℃ in 2022. Given the similar patterns of results between the two waves, data from the two waves were combined in the analyses reported below. The combined sample size was sufficiently powered to detect an effect size of $B = 0.006$ with power = .88 and $\alpha = .05$ (using "SIMR" package in R project; Green & MacLeod, 2016).

2.1.2 Procedure

This study consisted of a baseline phase, 10 days of time-sampling, and an exit phase. At the baseline phase (Day 0), we did an in-home interview asking about participants' demographic information and introduced the procedure for the subsequent 10-day time sampling study. From Day 1 to Day 10, participants completed short questionnaires on their current affect, the activities they were engaged in, and their meaningful engagement in these activities three times a day. They were signaled by a smartphone app at random times in the morning, afternoon, and evening, with at least four hours between successive questionnaires. Reminders would signal every fifteen minutes until the end of the one-hour interval if the participant had not completed a questionnaire. During the 10-day sampling period, participants carried a button sensor with them to detect the instantaneous temperature in their immediate environment. During the exit phase (Day 11), we visited the participants again to retrieve the devices and debrief the participants.

With this time sampling design, we obtained repeated assessments of individuals' affect over time when they were exposed to various instantaneous temperatures as they carried out their everyday activities during the 10-day period.. This enabled us to examine whether the instantaneous temperature of individuals' immediate environment was associated with their moment-by-moment emotional well-being and whether their momentary meaningful

engagement might moderate this association (within-person analysis). We also examined whether these effects were different across different individuals (between-person analysis).

2.1.2 Measures

Positive and negative affect. This measure is adopted from Tsai et al. (2006)'s Affect Valuation Index. Participants indicated their current affect by answering questions of the form, "how _ are you feeling right now?". Three positive affect states (happy, relaxed, satisfied) and four negative affect states (irritated, bored, lonely, stressed) were each evaluated from 0 ("not at all") to 100 ("very much"). The composite positive affect score was calculated by taking the mean of the three positive states, then rescaling this to a 0-20 range, making the scale comparable to that of instantaneous temperature to prevent model convergence issues. The same was done to create the composite negative affect score.

Meaningful engagement. Participants indicated one main activity they were doing during the period from the previous questionnaire to the present by selecting from a checklist of nine activity categories (i.e., social, physical, cognitive, self/health care, volunteering, passive leisure, work, snapping, or other activities). They then evaluated: 1. how meaningful the activity was to them and 2. how engaged they were in the activity on a scale from 0 ("not at all") to 100 ("very much"). Meaningful engagement was calculated as the average of the scores of these two items. Each person's meaningful engagement score was then centered on the person mean to produce a score for within-person level meaningful engagement. This reflects the participant's level of meaningful engagement at that moment. Moreover, the person mean score of meaningful engagement was used to capture their trait-like, between-person level meaningful engagement. This reflects the participant's overall meaningful engagement level. Both final scores were rescaled to a 0-20 range.

Instantaneous temperature. Instantaneous temperature of participants' immediate environment was measured by an iButton temperature/humidity logger (model DS1923-F5#-ND) attached to a keychain hung on their handbag. To account for random measurement error, we calculated the mean instantaneous temperature collected within the two hours right before participants answered the questionnaire, for analysis.

Objective and subjective SES. Household income was measured as an indicator of participants' objective SES. Participants indicated their household income per month by selecting from eight categories ranging from "0 – 3,000 HKD" to "> 100,000 HKD." Subjective SES was measured using the MacArthur scale (Adler et al., 2000), which use a 10-rung social ladder, with 1 representing "people who have the lowest income, live in the poorest conditions, and have the least decent jobs in society", 10 representing "people who have the highest income, live in the best conditions, and have the most decent jobs in society." Participants were asked to indicate their position on the ladder (1 = lowest, 10 = highest).

Demographics and covariates. Participants reported their gender, age, education level (five categories: primary school or below, high school, some college, bachelor's degree or above, and others), marital status (married vs. other statuses), and health status. For health status, participants evaluated their physical health, psychological health, and well-being from 1("Poor") to 5("Excellent"), and their scores across these three items were averaged to derive a measure of overall health status. Age, gender, overall health status, and the year they participated in the study were included as covariates. Gender and year were statistically controlled for because the samples from the two years were slightly different in their gender and SES distributions. The 2021 sample included more participants from lower SES families and more female participants, compared to the 2022 sample. Health status was controlled for

because heath might simultaneously affect older adults' emotional well-being and meaningful engagement (Tierney & Beattie, 2020).

2.2 Analysis plan

As there were around 30 time samplers for each participant (they completed the questionnaire 3 times per day for 10 days), we used multilevel modeling to account for the nested data structure (Level 1: within-person level, Level 2: between-person level). Positive and negative affect, within-person meaningful engagement, and instantaneous temperature are Level-1 variables. Between-person meaningful engagement, SES and other demographic variables are Level-2 variables.

We used bootstrapping with 5,000 resamples to estimate the confidence intervals and bootstrapped *p* values. First, we tested the main effects of instantaneous temperature, and within-person and between-person meaningful engagement, on positive and negative affect. Next, we examined the two-way interactions of instantaneous temperature with both levels of meaningful engagement. Lastly, we examined the three-way interactions between instantaneous temperature, objective SES (or subjective SES, examined in a separate model to prevent collinearity issues), and both levels of meaningful engagement. The results for models with objective and subjective SES are consistent with each other. For parsimony, this paper presents the results using objective SES, and the results using subjective SES can be found in Supplementary Table 2 in Online Supplementary Material.

2.3 Results

Positive and negative affect had intraclass correlations (ICCs) of .737 and .782, indicating that individual differences contributed substantially to their variances (73.7% and 78.2%, respectively). The model estimates are shown in Table 2.

Model 1 includes the main effects of instantaneous temperature, the two levels of meaningful engagement, and objective SES on positive and negative affect, controlling for gender, age, health status, and year. The main effects of all key variables were statistically significant. Consistent with H1, hotter instantaneous temperature was associated with less positive affect and more negative affect. Consistent with H2, higher meaningful engagement at both levels were associated with more positive affect and less negative affect. This indicates that meaningful engagement was beneficial for momentary emotional well-being, and people with higher levels of meaningful engagement on average tended to have better overall emotional-being.

Model 2 tested the two two-way interactions between instantaneous temperature and each level of meaningful engagement. For positive affect, both interactions were nonsignificant. For negative affect, there was a significant interaction between between-person meaningful engagement and instantaneous temperature. The effect of instantaneous temperature was non-significant among people with higher between-person meaningful engagement (b = 0.01, *95% CI* [-0.03, 0.07], p = .48), but was significant and positive among people with lower between-person meaningful engagement (b = 0.07, *95% CI* [0.03, 0.11], p < .001). In other words, older adults who had more meaningful engagement on average were more resilient to the adverse effects of hotter temperature on negative affect. The findings partially supported H3.

Model 3 tested two three-way interactions between instantaneous temperature, the two levels of meaningful engagement and objective SES (H4). For positive affect, both three-way interactions were non-significant. For negative affect, the three-way interaction concerning between-person meaningful engagement was significant. Echoing Model 2, between-person meaningful engagement buffered against the effect of hotter instantaneous temperature on negative affect. Furthermore, this buffering effect was stronger among participants with

lower objective SES than those with higher SES (see Figure 1). For people with higher SES, the effects of instantaneous temperature on negative affect were not significantly different at different levels of meaningful engagement (low: $b = 0.03$, *95% CI* [-0.03, 0.09], $p = .31$; high: $b = 0.04$, *95% CI* [-0.01, 0.09], $p = .13$). For people with lower SES, the effect of instantaneous temperature was non-significant among people with high meaningful engagement ($b = -0.03$, *95% CI* [-0.09, 0.03], $p = .39$), and it was significant and positive among people with low meaningful engagement ($b = 0.12$, *95% CI* [0.06, 0.17], $p < .001$).

3 Discussion

This study examined the impacts of hot instantaneous temperature on older adults' emotional well-being and the buffering effect of meaningful activity engagement in daily life. As expected, hotter instantaneous temperature during the summer months of a densely populated city with a tropical climate was negatively associated with older adults' emotional well-being (H1). Meaningful engagement at the between-person and within-person levels both contributed to better emotional well-being (H2), but only the former buffered against the adverse impacts of hotter instantaneous temperature (H3). For older adults with low meaningful engagement, hotter instantaneous temperature positively predicted their negative affect. For older adults with high meaningful engagement, the effect of hotter temperature was non-significant. We can infer from these results that momentary meaningful activity engagement may be sufficient to boost older adults' affect at that moment; but in order to foster psychological resilience to hot weather, longer-term meaningful engagement is necessary. As suggested by vital engagement theory, when people engage in something meaningful at the moment, they feel absorbed and intrinsically rewarded, and thus experience increased pleasantness. This may explain why meaningful engagement at both the between-person and within-person levels of our study predicted better emotional well-being. Yet, the theory also postulates that. the continuous participation in meaningful and engaging activities

is likely to enable individuals to develop interests, expertise, a sense of mastery, and purpose, and, in turn, foster long-term well-being (Nakamura, 2001). It may be this mechanism that allows older adults with higher between-person meaningful engagement in our study to show greater resilience against hot temperature. Our findings echo previous arguments that continued active engagement in life is one crucial criterion to positive aging (Rowe & Kahn, 1998). They are also consistent with previous findings that prolonged engagement in flow-eliciting activities is associated with enhancement of functioning and well-being (e.g., life satisfaction; Landhäußer & Keller, 2012). Our study advances the positive aging literature by highlighting the important role of meaningful activity engagement in enhancing psychological resilience to hot temperatures.

Furthermore, we found that the buffering effect of meaningful engagement was more prominent among older adults with lower SES (H4). Additional analyses (Refer to Online Supplementary Material Table 4) showed that SES negatively correlated with overall instantaneous temperature (r = [-.168, -.144], p < .001). This indicates that compared to older adults with lower SES, those with higher SES are more able to keep their instantaneous temperature at a lower level during hot days. Given that older adults with higher SES are better able to physically control their instantaneous temperature, or to be in a cooler environment, engaging in meaningful activity as psychological buffer may be less essential to them. Conversely, people with lower SES have fewer resources and options to cool down their instantaneous temperature. Hence, the buffering effect of meaningful engagement may be more salient to them. Additionally, we found that objective SES showed no association with between-person meaningful engagement (r = .086, p = .112). This suggests that lower SES is not a barrier to meaningful engagement. This finding contributes to the vital engagement literature by suggesting that meaningful engagement is not the privilege of rich and successful people. Regardless of SES, anyone can find personally meaningful activities

to engage in, which could help them cope with the uncomfortable feelings brought by hot temperature. Hence, meaningful engagement may help narrow the gap between older adults with different SES backgrounds in their psychological vulnerability to extremely hot weather.

Health is an important contributor to both older adults' emotional well-being and meaningful engagement (Tierney & Beattie, 2020). Even after controlling for health, the protective effect of between-person meaningful engagement was still significant. Moreover, health did not moderate the negative effects of hot temperature on emotional well-being (Refer to Supplementary Table 3 in Online Supplementary Material). This indicates that the buffering effect of meaningful engagement is not simply due to people with higher levels of meaningful engagement having better health. Future research should investigate how meaningful engagement provides distinct benefits beyond those of health status, and the mechanisms through which meaningful engagement boosts older people's psychological well-being. Potential mechanisms, based on SST and SDT, include fostering meaning in life (Eakman, 2013) and meeting basic psychological needs (Kowal & Fortier, 1999). As argued by the Meaningful Activity and Meaning in Life (MALM) model (Eakman, 2013), a person's daily engagement in meaningful activities satisfies their needs for autonomy, competence, and relationship, thus comprising their life meaning and psychological well-being.

Strengths, limitations, and future directions

First, this time sampling study has high ecological validity. By linking momentary psychological responses with real-time objective instantaneous temperature, we were able to detect fluctuations in older adults' daily affect with temperature and identify older adults with higher resilience or vulnerability to hot temperature. Moreover, this design enabled us to disentangle between- and within-person effects of meaningful engagement. However, we should be cautious in drawing causal conclusions from this design. Although there was a time

lag between meaningful engagement and current affect reports (i.e., participants' meaningful engagement happened before they reported their current affect), there was no experimental control or manipulations. Future studies can manipulate activity meaningfulness to examine potential causal relationships between meaningful engagement and psychological well-being.

Second, this study examined the impact of hot weather from a microenvironmental perspective. Previous research examined the relationship between weather and well-being from a macro perspective using population data and district-level weather data (Kööts et al., 2011). However, even for people in the same area (district) sharing the same outdoor temperature, the extent to which they are exposed varies greatly, as people differ in their ability to adjust their environments. On a given day with high outdoor temperature, some people may stay in an air-conditioned room, whereas others may work in a non-air-conditioned environment. People also move around. Hence, in contrast to district temperature, our participants' instantaneous temperature reflects their microenvironments, which affect their well-being more directly. Hence, this study filled a knowledge gap in this field. Future studies can combine district temperature and participants' instantaneous temperature to further investigate how people differentially cope with hot temperature.

Third, this study establishes the negative impacts of hot instantaneous temperature on emotional well-being and the buffering effect of meaningful engagement. Hong Kong suffers from some of the most severe economic inequality and extremely hot temperatures (United Nations Development Programme, 2022). Older adults, especially those with lower SES, are the most vulnerable; hence, it is very important to find feasible psychological strategies for them to deal with hot weather. The present study is the first to find that meaningful engagement, which has previously been shown to contribute to older adults' well-being (Eakman et al., 2010), is also an effective buffer against the psychological effects of hot temperature. Meaningful engagement is a simple and cost-effective strategy that may help

individuals with fewer resources cope with extreme temperatures that are outside their control.

A limitation of this study is that we only examined buffering effects of meaningful engagement on emotional well-being; whether it could also protect one's physical well-being from extreme weather remains unknown. Additional analyses found that meaningful engagement was positively associated with self-reported physical health (Refer to Supplementary Table 4 in Online Supplementary Material). Yet, causal direction cannot be determined. Future studies should adopt physical health-related indicators such as heart rate variability to examine whether meaningful engagement may have a tangible impact on physical health.

To further investigate the effects of meaningful engagement on psychological well-being, two questions are worth exploring. First, which activities are meaningful and engaging for older adults? Our additional analyses showed that social, physical, and volunteering activities were the three most meaningful and engaging activities reported by older adults (Refer to Supplementary Table 5 in Online Supplementary Material). Future research can further explore the reasons why these activities are more meaningful than others and whether the perceived meaningfulness of a given activity varies between individuals. A dispositional-situational approach can be used to create personalized meaningful activity inventories tailored to individuals' dispositions.

Conclusion

Climate change affects everyone, especially older adults with lower SES. Fortunately, these individuals are not powerless against hot temperature. Meaningful engagement, over the long term, appears to be a viable strategy for dealing with these extreme temperatures. This strategy is available, and in fact is more effective, for people with fewer resources.

Moreover, it can be tailored to suit individuals' unique ideas of what sorts of activities are personally meaningful. Hence, meaningful engagement can become a practical, cost-effective, flexible, and readily-available means of reducing social inequality in well-being amid climate changes.

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Conflict of Interest

None reported.

Data Availability

The study in this article is aligned with open practices of scientific research. Materials, data, and code are publicly accessible at: https://osf.io/cn9zs/?view_only=d0161eb2337346f19db3096624faeb5b.

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Table 1. *Demographic Information for the 2021 and 2022 Samples.*

Variable	Year 2021 (n = 171; k = 4,779)		Year 2022 (n = 150; k = 4,503)		Overall (N = 321; k = 9,282)	
	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%
Age	67.77 (5.41)		66.40 (4.99)		67.15 (5.26)	
Sex (female)		63.9		51.6		58.3
Educational level						
Primary school or below		12.9		8.3		10.8
Junior (high) school		53.6		50.9		52.3
Some college		10.0		21.7		15.4
Bachelor's degree or above		19.4		17.6		17.0
Others		7.1		1.7		4.6
Relationship status (married)		63.4		70.7		66.7
Household income per month (HKD)						
0 - 3,000		9.8		8.9		9.5
3,001 - 8,500		25.1		12.7		19.6
8,501 - 14,000		14.8		17.2		16.0
14,001 - 20,000		12.6		12.7		12.8
20,001 - 30,000		15.3		15.3		15.4
30,001 - 60,000		17.5		17.2		17.5
60,001 - 100,000		3.3		10.2		6.5
> 100,000		1.6		3.8		2.7
Instantaneous temperature (℃)	28.19 (2.19)		28.08 (2.36)		28.14 (2.28)	

Note. k = number of observations.

Table 2. *Unstandardized estimates and 95% confidence intervals for multilevel models predicting positive and negative affect.*

Outcome	Predictor	Model 1	Model 2	Model 3
Positive affect	Instantaneous temperature (IT)	-0.026*	-0.079	-0.188
		[-0.049, -0.004]	[-0.207, 0.048]	[-0.510, 0.133]
	Within-level meaningful engagement (WME)	0.285***	0.089	-0.155
		[0.248, 0.320]	[-0.187, 0.362]	[-0.840, 0.538]
	Between-level of meaningful engagement (BME)	0.732***	0.638***	0.434
		[0.668, 0.794]	[0.392, 0.879]	[-0.166, 1.050]
	Income	0.111*	0.112*	-0.931
		[0.006, 0.216]	[0.008, 0.217]	[-2.945, 1.077]
	IT × WME		0.007	0.017
			[-0.003, 0.017]	[-0.008, 0.041]
	IT × BME		0.003	0.008
			[-0.005, 0.012]	[-0.013, 0.029]
	IT × Income			0.028
				[-0.042, 0.098]
	WME × Income			0.057
				[-0.089, 0.204]
	BME × Income			0.051
				[-0.080, 0.179]
	IT × WME × Income			-0.002
				[-0.007, 0.003]
	IT × BME × Income			-0.001
				[-0.006, 0.003]
	$Var_{Intercept}$	14.344	14.469	14.130
	Var_{IT}	0.015	0.015	0.015
	Var_{WME}	0.060	0.060	0.060
	$Var_{Residual}$	2.413	2.411	2.411
	$R^2_{Fixed\ effect}$	.540	.540	.542
Negative affect	IT	0.043**	0.193*	0.643***

Outcome	Predictor	Model 1	Model 2	Model 3
		[0.015, 0.070]	[0.036, 0.341]	[0.268, 1.023]
	WME	-0.202***	-0.258	0.096
		[-0.239, -0.164]	[-0.550, 0.042]	[-0.689, 0.872]
	BME	-0.697***	-0.426**	0.480
		[-0.802, -0.591]	[-0.715, -0.141]	[-0.229, 1.195]
	Income	-0.216*	-0.217*	3.082**
		[-0.392, -0.037]	[-0.393, -0.037]	[0.704, 5.458]
	IT × WME		0.002	-0.011
			[-0.008, 0.012]	[-0.039, 0.016]
	IT × BME		-0.010**	-0.039**
			[-0.020, -0.0001]	[-0.064, -0.014]
	IT × Income			-0.107**
				[-0.190, -0.025]
	WME × Income			-0.080
				[-0.240, 0.085]
	BME × Income			-0.213**
				[-0.366, -0.060]
	IT × WME × Income			0.003
				[-0.003, 0.009]
	IT × BME × Income			0.007**
				[0.002, 0.012]
	$Var_{Intercept}$	23.254	22.987	22.540
	Var_{IT}	0.025	0.025	0.024
	Var_{WME}	0.059	0.059	0.059
	$Var_{Residual}$	2.996	2.995	2.994
	$R^2_{Fixed\ effect}$	.353	.358	.360

Note: $N = 321$, k (number of observations) = 9,282. Gender, health status, age, and year were included as covariates. The estimates for covariates can be found in Supplementary Table 1 in Online Supplementary Material. $Var_{Intercept}$, Var_{IT}, Var_{WME} and $Var_{Residual}$ are the variances of intercept, slopes of instantaneous temperature, momentary-level meaningful engagement, and residual. $R^2_{Fixed\ effect}$ represents the proportion of the variance for the dependent variable that is explained by the independent variables listed in the model.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 1. Three-way interaction between temperature, between-level meaningful engagement, and household income on positive and negative affect.

Note. For both between-level meaningful engagement and household income, “Low” means 1 standard deviation (SD) below the mean score, “High” means 1 SD above the mean score. The gray shadow represents the 95% confidence intervals.

Figure 1