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The environmental cost of misinformation: why the recommendation to use elevated temperatures for handwashing is problematic

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Abstract

Multiple government and health organizations recommend the use of warm or hot water in publications designed to educate the public on best practices for washing one's hands. This is despite research suggesting that the use of an elevated water temperature does not improve handwashing efficacy, but can cause hand irritation. There is reason to believe that the perception that warm or hot water is more effective at cleaning one's hands is pervasive, and may be one factor that is driving up unnecessary energy consumption and greenhouse gas emissions. We examine handwashing practices and beliefs about water temperature using a survey of 510 adults in the US. The survey included measures of handwashing frequency, duration, the proportion of time an elevated temperature was used and beliefs about water temperature and handwashing efficacy. We also estimate the energy consumed and resultant carbon dioxide equivalent emissions (CO_2eq) in the US due to the use of elevated temperatures during handwashing. Participants used an elevated temperature 64% of the time, causing 6.3 million metric tons (MMt) of CO_2eq, which is 0.1% of total annual emissions and 0.3% of commercial and residential sector emissions. Roughly 69% of the sample believed that elevated temperatures improve handwashing efficacy. Updating these beliefs could prevent 1 MMt of CO_2eq annually, exceeding the total emissions from many industrial sources in the US including the lead and zinc industries. In addition to causing skin irritation, the recommendation to use an elevated temperature during handwashing contributes to another major threat to public health – climate change. Health and consumer protection organizations should consider advocating for the use of a 'comfortable' temperature rather than warm or hot water.

Introduction

Due to the growing cost of energy and increasing concerns over the environmental impact of energy production, energy conservation has become an increasing focus of businesses, consumers and consumer advocates around the world. Of particular concern is the growing body of work documenting the enormous economic and health threats posed by climate change (Intergovernmental Panel on Climate Change, 2007). To lessen these impacts, greenhouse gas (GHG) emissions must be quickly stabilized and drastically reduced over the coming decades. A recent report from a panel convened by the US National Research Council recommended a 50–80% decrease of US GHG emissions below 1990 levels by 2050 (America's Climate Choices: Panel on Limiting the Magnitude of Future Climate Change, 2010). A more ambitious target of an 80–95% reduction by 2050 has been proposed in the European Union (European Commission, 2012). Efforts to improve conservation and efficiency within the household and commercial sectors will be critical to meeting these targets, and may represent one of the most cost-effective options available for achieving near-term emission reductions (Bressand *et al*., 2007; Gardner and Stern, 2008; Vandenbergh *et al*., 2008; Dietz *et al*., 2009). As such, a challenge for researchers is to identify sources of emissions that can reduce consumer energy costs and contribute to the necessary level of reductions in GHG emissions.

A number of researchers and conservationists have turned to water use as one opportunity for reducing emissions (Biermayer, 2005; Somner *et al*., 2008; Clarke *et al*., 2009). The provision of clean water alone requires a substantial amount of energy to remove pathogens and to deliver water to the user's tap. The additional energy required to heat water accounts for approximately 15% of residential energy use in both the US and the European Union, second only to space heating and cooling (U.S. Environmental Protection Agency, n.d.; European Environment Agency, 2011). There are significant opportunities for reducing household energy use by reducing hot water consumption during routine activities such as laundry (e.g. Laitala *et al*., 2011, 2012). For example, Laitala *et al*. (2011) found that laundry carried out at 30°C cleans as effectively as laundry carried out at the more commonly used 40°C, uses nearly 30% less energy, and reduces wear and tear on clothing. Researchers at the University of Bonn have found that consumers who followed 10 'Best Practice Tips' during manual dishwashing reduced their energy use during this activity by 70% (Fuss *et al*., 2011).

Relatively little attention has been given to handwashing as an opportunity for reducing energy consumption (for an exception, see Somner *et al*., 2008). Although the amount of energy used for handwashing is relatively small in comparison to other water using behaviours, there is reason to believe that the amount of energy is inflated due to the misperception that warm or hot water improves the efficacy of washing one's hands. This is particularly true in North America and Western Europe, where there is a strong cognitive connection between water temperature and hygiene relative to other countries, such as Japan, where warm or hot water is used primarily for comfort (Wilhite *et al*., 1996). Although the perception that hot water is more hygienic is based in some factual evidence, the literature reviewed below suggests that there are few, if any, hygienic benefits of using warm or hot water to wash one's hands. Despite this, well-intentioned public health advocates have perpetuated this perception by recommending to consumers that they wash their hands with warm or hot water, potentially driving up unnecessary energy consumption without providing health benefits to the consumer. In this study, we examine Americans' perceptions of water temperature and handwashing efficacy, as well as self-reported handwashing practices. The potential reductions in energy use and GHG emissions that could be saved in the US by updating these beliefs are estimated below. We conclude with recommendations for consumer advocates and health agencies.

Water temperature and handwashing

Washing one's hands may be the single most important means of preventing the spread of infectious disease and protecting families from illness. Multiple government and health organizations offer instructions for how to most effectively wash hands to eliminate pathogens. This typically includes the application of soap, vigorous rubbing for 15–20 s, rinsing and drying with a towel or air dryer (National Health Service, n.d.; European Centre for Disease Prevention and Control, 2009; U.S. Department of Health and Human Services, 2008). Although many prominent health organizations such as the World Health Organization, the US Centers for Disease Control and Department of Health, England, do not specify a water temperature in their instructions for handwashing, numerous other well-known organizations specifically recommend the use of 'warm' or 'hot' water. For example, on web sites and pamphlets aimed at the general public, the US Food and Drug Administration (FDA), the American Society for Microbiology and Health Canada all recommend the use of an elevated water temperature.[1] Not surprisingly, these recommendations have been cited by smaller public health departments and advocacy groups and have become the standard for acceptable or, in some cases, required handwashing practice. The 2005 US FDA Food Code not only requires the use of warm water, but also requires handwashing sinks to reach a temperature of no less than 38°C (100°F) (U.S. Food and Drug Administration, 2005). Failure to meet these standards can result in the accumulation of violations and eventual closure of food establishments.

Despite what is commonly advocated, there are no known data to support the claim that water temperature is associated with handwashing efficacy. It is true that heat kills bacteria; however, the level of heat required to neutralize pathogens is beyond what is considered safe for prolonged human contact. Water considered 'hot' for the purposes of handwashing has been estimated to be within the range of 40–55°C (104–131°F) (Rothenborg *et al*., 1977; Herrmann *et al*., 1994; Michaels *et al*., 2001). Although the high end of this estimate is sufficiently hot to neutralize some pathogens, it could not be sustained for a long enough period without causing serious harm. Common pathogens such as *Escherichia coli*, *Salmonella typhimurium* and *Klebsiella pnumonae* stay alive at temperatures up to 55°C (131°F) for over 10 min and *Staphylococcus aureus* would require at least 50 min of exposure at a temperature of 60°C (140°F) to be reduced to an immeasurable level (Angelotti *et al*., 1961; Spinks *et al*., 2006). By comparison, just 30 s of skin exposure to water heated to 55°C would cause deep second-degree burns, and water heated to 60°C could be tolerated for less than 6 s before causing serious harm.

It has also been claimed that higher water temperatures are more effective at removing bacteria-containing oil and dirt (U.S. Food and Drug Administration, n.d.). Price (1938) examined microbial counts after hand scrubbing at various water temperatures between

[1]For example, the U.S. Department of Agriculture on its 'Teamnutrition' web site recommends washing hands under 'warm running water' (http://teamnutrition.usda.gov/Resources/how_to_washhands.pdf), as does the American Society for Microbiology (http://www.microbeworld.org/images/stories/washup/downloads/2008handhygienedontgetcaught_000.pdf). Health Canada on its web site 'The Benefits of Hand Washing' recommends wetting and rinsing hands with 'warm water' http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/diseases-maladies/hands-mains-eng.php#how. The Iowa Department of Public Health recommends using soap and 'warm or hot running water,' and states that 'cold water and a quick rub' is not effective and that 'you need to use warm water and soap to get the oil and germs off your skin' (http://www.idph.state.ia.us/idph_universalhelp/MainContent.aspx?glossaryInd=0&TOCId=%7B9D095B70-9494-482E-BCE7-A50A635DDB6A%7D). The US FDA recommends the use of 'hot, soapy water' for adults and 'warm, soapy water' for kids (http://www.fda.gov/ForConsumers/ByAudience/ForWomen/ucm118524.htm?utm_campaign; http://www.fda.gov/Food/ResourcesForYou/StudentsTeachers/ScienceandTheFoodSupply/ucm215837.htm). Similarly, multiple local- and state-level organizations including the New York State Department of Health (http://www.health.ny.gov/publications/7096.pdf), the Wisconsin Department of Health Services (http://www.cabq.gov/environmental health/food-safety/restaurant-food-safety), the City of Albuquerque (http://www.cabq.gov/envhealth/foodsafety.html) and the University of Arizona (http://extension.arizona.edu/sites/extension.arizona.edu/files/resourcefile/resource/lbrandman/Proper%20Handwashing2.pdf) also recommend using hot water. Interestingly, the University of Arizona suggests a water temperature 'as hot as you can stand it' and specifies a range of '100–110°F' (38–43°C).

24°C (75°F) and 56°C (133°F) and found no difference in the rate of germ removal. More recent studies using updated methods support Price's findings (Larson *et al*., 1980; Michaels *et al*., 2001, 2002). Although some soap may emulsify better with warmer water, these gains appear to be overwhelmed by the process of scrubbing, rinsing and drying the hands. Michaels *et al*. conducted a series of studies in which soiled hands were washed with a common non-antibacterial soap under various temperature conditions between 4.4 and 50°C (Michaels *et al*., 2001, 2002). They found no significant differences in the levels of bacterial reduction as a function of temperature. This procedure was repeated using four antibacterial soaps with different active ingredients, and although the level of bacterial reduction was slightly higher in the high temperature condition, no significant differences were found. These findings have led to the conclusion that warm water should not be advocated for its antimicrobial properties (Laestadius and Dimberg, 2005; World Health Organization, 2009).

Although there appear to be no direct health benefits associated with the use of elevated temperatures, indirect benefits may exist among those who find warmer temperatures more comfortable and may, therefore, wash their hands more frequently or for longer durations. However, advocating for the use of warm or hot water, rather than a 'comfortable' temperature, may lead to the misperception that proper hygiene can only be achieved using elevated temperatures. Perceptions of comfort may shift according to consumer preference and ambient temperature, and some consumers may be willing to sacrifice comfort in order to save money or reduce their environmental 'footprint'. There may also be negative health impacts of this recommendation. Advocating the use of elevated temperatures, particularly 'hot' water, may lead some to choose temperatures that are higher than what is comfortable, potentially leading to scalding. Furthermore, elevated temperatures, even within a range that most would consider comfortable (i.e. 37°C vs. 40°C) can lead to skin irritation when paired with many common hand soaps (Rothenborg *et al*., 1977; Emilson *et al*., 1993; Ohlenschlaeger *et al*., 1996; Clarys *et al*., 1997). In addition to causing pain, the damage to the protective barrier of the skin that results can cause the skin to be less resistant to bacterial colonization. For example, nurses with irritated hands were significantly more likely to be colonized with a number of potentially harmful bacteria, including *S. aureus* (Larson *et al*., 1998; Cook *et al*., 2007). Hand irritation is also a commonly cited reason among nurses for not washing their hands as often as recommended (Larson and Killien, 1982; Pittet *et al*., 1999).

Research objectives and study overview

Previous research has found that, in some cases, well-intentioned behaviours based on misperceptions or outdated beliefs can lead to outcomes that are against the consumer's own economic interests and unnecessary environmental impacts (Carrico *et al*., 2009). We examine beliefs regarding water temperature and hand hygiene using a survey of American adults. Perceptions of the cleaning benefits of various water temperatures are measured, and we examine how they relate to self-reported handwashing behaviour. These measurements serve as the basis of an estimate of energy use and GHG emissions that result from the use of warm or hot water for handwashing in the US.

Table 1 Demographic profile of sample and population

	Sample	Population[a]
Gender (% female)	46%	51%
Age (median)	44	37
Education (median)	Some college	Some college
Income (median)	\$50 000–\$74 999	\$50 000
Food service industry	3%	8%
Health care industry	8%	5%

[a]Population estimates for gender, age, education and income are based on 2008 data from the U.S. Census Bureau (U.S. Census Bureau 2009a,b). The proportion of food service and health-care employees are based on Bureau for Labor Statistics (2009).

Methods

Participants

Participants were adults (18 and over) living in the US recruited during the spring of 2009 from an online research panel.[2] Of the 515 individuals who logged in to complete the survey, 510 provided usable data. Table 1 presents the demographic profile of this sample as compared with population estimates. The sample was representative with the exception of age. Previous studies suggest there are few, if any, age differences in handwashing practices among adults (American Society for Microbiology, 2005, 2007); therefore, this sampling bias is considered trivial. In addition, food service workers were slightly under-represented and health-care workers were slightly over-represented. However, the two groups combined (both are required to wash their hands more frequently than the general population) made up 11% of the sample as compared with 13% of the population.

Procedure

Prospective participants were invited via e-mail to participate in a study about handwashing. Those who agreed were directed to a web site where they completed a survey regarding their typical handwashing practices, beliefs about the efficacy of various handwashing techniques and attitudes towards handwashing. The survey took roughly 5–10 min to complete.

Measures

Demographic information

Information about the participant's age, gender, education and income were collected. Respondents reported their annual household income before taxes using one of six categories, 'less than \$15 000', '\$15 000–\$24 999', '\$25 000–\$34 999', '\$35 000–\$49 999', '\$50 000–\$74 999' and '\$75 000 and above'. Participants also indicated the highest level of education they had completed on a six-item response scale including, 'less than high

[2]All participants were recruited from eLab, an online research panel managed by Vanderbilt University's Owen Graduate School of Management. This panel includes over 50 000 users worldwide who have volunteered to participate in online research studies. More information about this research panel can be found at http://elab.vanderbilt.edu/.

school degree', 'high school degree', 'some college/associate's degree', 'college degree', 'some postgraduate work' or 'postgraduate degree'.

Handwashing behaviour

Participants indicated how many times during the previous 24 h that they washed their hands (frequency) and the average time spent during each handwash (duration). The use of an elevated temperature during handwashing was classified as any time an individual selected the 'warm' or 'hot' option at the faucet. To measure this, participants were asked to indicate the proportion of time that they used 'warm or hot water' at the faucet to wash their hands (proportion elevated).

Handwashing beliefs

Participants were asked to rate the effectiveness of five different water temperatures at cleaning one's hands, including cold water (12.8–18.3°C/55–65°F), cool water (18.3–23.9°C/65–75°F), room temperature water (23.9–29.4°C/75–85°F), warm water (29.4–35°C/85–95°F) and hot water (35–40.6°C/95–105°F). Responses were made on a 5-point scale ranging from 1 ('not at all effective') to 5 ('highly effective').

Handwashing motivations

Five items assessed the reasons for which individuals chose a particular handwashing temperature. First, participants were asked to indicate to what extent they 'make a conscious decision or choice about water temperature'. Response options ranged from 1 ('almost never') to 5 ('almost always'). Next, participants were asked to indicate to what extent they would attribute their choice of water temperature to: cleanliness, comfort, habit and availability. Responses ranged from 1 ('not at all') to 5 ('very much').

Results

Preliminary analysis

Calculations for determining the amount of energy and GHG emissions required to heat water for handwashing are provided in the Appendix. These estimates suggest that, considering fuel sources and efficiency (see Section 3 of the Appendix) each litre of heated water requires roughly 244 kilojoules (kJ) of energy and results in 0.02 kilograms (kg) of carbon dioxide equivalent (CO_2eq; or 0.08 kg/gallon).[3] Calculations based on faucet flow rate and use find that 0.11 l of water is used for each second of a handwash.

To calculate the average time an individual uses an elevated temperature, the frequency, duration and proportion elevated were estimated. Due to the tendency for individuals to over-report handwashing (American Society for Microbiology, 2005, 2007), these data were aggressively screened for outliers. Values that were clearly out of range were first excluded, including those who reported washing their hands more than 30 times a day (*n* = 5) or for an average duration of 1 min or more (*n* = 80). Next, values that fell beyond two standard deviations above the mean were excluded.[4] This includes individuals who reported washing their hands more than 25 times a day (*n* = 19) or for an average duration of 46 s or longer (*n* = 6). These estimates resulted in an average frequency of eight handwashes per day, an average duration of 21 s and the use of an elevated temperature 75% of the time.

It is likely that our estimates are inflated due to social desirability bias. We are aware of only two studies that have measured handwashing duration within the general population. One took place in shopping malls in Japan and found an average duration of 14 s (Toshima *et al*., 2001). In the second one, individuals were observed in public restrooms at a large university in the US and found that the average person washed their hands for 4–6 s (Monk-Turner *et al*., 2005). To be conservative, and because cultural differences may partially account for the discrepancy between these estimates, it is assumed that the population observed in this latter study better reflects the behaviour of the average American. Because this estimate is drastically lower than estimates collected in other settings (Taylor, 1978; Toshima *et al*., 2001), the high end of this range (6 s) was substituted as the estimated average duration.

No known studies that have measured handwashing frequency or the use of elevated water temperatures. Surveys commissioned by the American Society for Microbiology (ASM) used both self-report and behavioural observation to assess the proportion of time Americans wash their hands in various situations (American Society for Microbiology, 2005, 2007). Between 91% and 95% of Americans reported 'always' washing their hands after using a public restroom. Observations conducted in public restrooms throughout the US (e.g. airports, train stations) found that only 77–82% of those observed actually washed their hands, indicating that the general public tends to overestimate this behaviour by roughly 15%. To account for the tendency to over-report, self-reported frequency and the proportion elevated were adjusted downward by 15%. Therefore, we assume the typical American washes his or her hands seven times a day and uses warm or hot water 64% of the time.

Energy use and greenhouse gas emissions

To calculate the average minutes per day an individual uses warm or hot water during handwashing, the estimated number of handwashes per day (7) was multiplied by the estimated proportion of time individuals used an elevated temperature (64%) and the estimated average duration per handwash (6 s). This resulted in 27 s/person/day. Multiplying this figure by 365 days in the year and the roughly 304 million people currently living in the US (U.S. Census Bureau, 2009b) indicates that, each year, the use of elevated temperatures for handwashing accounts for roughly 276

[3]We estimate carbon dioxide, methane and nitrous oxide emissions, which are the three primary anthropogenic greenhouse gasses associated with the fuel sources used to provide hot water. The global warming impact of methane and nitrous oxide emissions is expressed in terms of carbon dioxide equivalents using Intergovernmental Panel on Climate Change standards for global warming potential as described in the Appendix.

[4]Because our primary concern was over-reporting of handwashing behaviour due to social desirability bias, scores that fell *below* two standard deviations from the mean were left in the sample. This allowed for a more conservative estimate of handwashing behaviour.

Table 2 Means and standard deviations for perceived effectiveness of water temperatures

	M	*SD*
Cold	2.18	1.13
Cool	2.46	1.09
Room temperature	3.09	1.03
Warm	4.01	0.85
Hot	4.44	0.96

M, mean; *SD*, standard deviation.
Note. Responses were made on a 5-point scale ranging from 'not at all effective' to 'highly effective'.

billion liters of water (73 billion gallons), 68 trillion kilojoules (kJ) of energy (65 trillion British thermal units, Btu), and roughly 6.3 MMt of CO_2eq. The parameters and calculations used to estimate water, energy use and GHG emissions are provided in the Appendix.

Beliefs about water temperature

The means and standard deviations for the perceived effectiveness of various water temperatures are provided in Table 2. In all cases, warmer temperatures were rated as more effective, with hot water rated as the most effective and cold water as the least. Based on the average ratings, hot water was believed to be more than two times as effective as cold water. Paired *t*-tests revealed that the rated effectiveness of each temperature was significantly different from the one above or below it,[5] suggesting a linear relation between water temperature and perceived cleaning ability. A direct comparison of the perceived effectiveness of room temperature vs. warm water showed that 69% of the sample ($n = 351$) believed warm water to be more effective and 28% ($n = 140$) believed it to be equally as effective as room temperature water. Only 2% ($n = 11$) thought that warm water was less effective than room temperature water.

Next, the proportion of time participants used warm or hot water during handwashing was compared between those who held accurate and inaccurate beliefs. Those who believed warm water was less effective were excluded from the analysis. A one-way analysis of variance (ANOVA) was used to compare the remaining two groups. On average, those who held accurate beliefs reported using warm or hot water 55% of the time, compared with 68% among those who held inaccurate beliefs, $F_{(1,489)} = 33.74$, $P < 0.01$ (means are adjusted downwards by 15%).

Although these data suggest that misperceptions are related to the use of elevated handwashing temperatures, the use of elevated temperatures was relatively high even among those who held accurate beliefs (55% of handwashes). This suggests that factors beyond cleaning effectiveness play an important role in an individual's decisions to use warm or hot water. When asked, the majority of respondents (70%, $n = 354$) reported that they do make a conscious decision about water temperature 'most of the time' (34%) or 'all of the time' (36%). Interestingly, participants ranked cleanliness as equally important ($M = 3.96$, $SD = 1.24$) as comfort ($M = 4.07$, $SD = 1.03$), habit ($M = 4.06$, $SD = 1.02$) and availability ($M = 3.88$, $SD = 1.18$).[6] Thus, the perceived importance of all four of these factors is equivalently high.

Conclusions

These data suggest that the use of elevated temperatures for handwashing is common practice. The average respondent reported using warm or hot water 64% of the time. Although the choice of water temperature during a single handwash may appear trivial, when multiplied by the nearly 8 billion handwashes performed by Americans each year, this practice results in over 6 MMt of CO_2eq annually. To put this figure in perspective, 6 MMt is roughly 0.1% of annual GHG emissions in the US and around 0.3% of the total annual emissions attributable to the commercial and residential sectors combined.[7] This value is roughly equivalent to the emissions of two coal-fired power plants, which emit around 3.8 MMt of CO_2eq a year (U.S. Environmental Protection Agency, 2009a). Not surprisingly, a large majority of the sample (69%) endorsed the belief that handwashing with warm water is more effective than room temperature water. Those who held this misperception indicated that they use warm water significantly more often than those who believed that water temperature does not affect handwashing efficacy. If updating beliefs would induce these individuals to use warm or hot water at the same level as those who hold accurate beliefs, US emissions could be reduced by nearly 1 MMt annually. These savings would be equivalent to eliminating total annual emissions from the zinc or lead industries in the US or the total emissions of any number of small countries including Malawi or Barbados (World Resources Institute, 2008; U.S. Environmnetal Protection Agency, 2009b).

Although 0.1% of annual GHG emissions may seem insignificant, even a seemingly trivial proportion of GHG emissions can be important given the ambitious emission targets that have been set and the improbability that these can be achieved by only focusing on large sources (Stack and Vandenbergh, 2011). Researchers and policy makers often prioritize actions based on their technical potential for saving energy. However, multiple scholars have argued for the need to consider both technical potential as well as behavioural plasticity – the likelihood that an action will be adopted by the consumer (e.g. Vandenbergh *et al*., 2008; Dietz *et al*., 2009). The latter depends, in part, on barriers to adoption such as up-front costs and the ease of engaging in an action. In line with these concerns, researchers have identified a number of actions that have the potential to deliver smaller yet non-trivial reductions in emissions that could be achieved rapidly and often with little economic or lifestyle sacrifices (e.g. Gardner and Stern, 2008; Carrico *et al*., 2009; Dietz *et al*., 2009). For this reason, behaviours such as handwashing, which are strongly influenced by

[5]One-tailed paired *t*-tests were used for this analysis using a *Bonferroni* adjustment to control for family-wise error. The alpha level was set at $P < 0.013$.

[6]All responses were made on a scale ranging from 1 (not at all) to 5 (very much). Paired *t*-tests indicated that the importance of cleanliness was not statistically different from comfort, habit or availability.

[7]According to the EPA's greenhouse gas inventory, in 2007, the US emitted 6088 MMt of CO_2eq. It has been estimated that direct behaviour of individuals and households accounts for approximately 38% of total US emissions, or roughly 2313 MMt annually (Gardner and Stern, 2008).

inaccurate information or misperceptions, may be good candidates for public information campaigns designed to update beliefs. The prevalence with which respondents reported using warm or hot water is not surprising, considering the frequency with which it is advocated. Multiple high profile organization examined for the purpose of this research, including the FDA, ASM and state public health agencies recommend using elevated water temperatures and, in some cases, cite its superior cleaning ability as the rationale (U.S. Department of Health and Human Services, 2008; U.S. Food and Drug Administration, n.d.). There is no doubt that the intention of these organizations is to promote a behaviour that is vital to protecting public health; however, the preponderance of evidence reviewed here suggests this recommendation provides no health benefit and may, in fact, negatively impact health. Climate scientists have warned that a rise in the average global temperature could result in a number of threats to human health, including increases in flooding, drought and infectious disease in some regions (Intergovernmental Panel on Climate Change, 2007). In addition to the impacts of climate change, elevated water temperatures are associated with skin damage and may contribute to bacterial colonization and reduced handwashing compliance. It is possible that the use of elevated temperatures may induce some individuals to wash their hands more frequently or for longer durations, therefore decreasing the spread of pathogens. For this reason, we suggest the public be encouraged to choose a 'comfortable' water temperature, so as not to imply that warm or hot water is somehow superior in its cleaning ability. Some individuals may prefer the use of warm or hot water, while others may decide that less elevated temperatures in the 'tepid' to 'warm' range are sufficiently comfortable. Although the degree of temperature was not measured in the current study, these data suggest that those who hold accurate beliefs do choose against selecting warm or hot water at the faucet on many occasions.

Given the importance of handwashing in preventing the spread of disease, we encourage consumer advocates and those in the field of public health to examine this issue more deeply. It is possible that there may be some situations in which the use of an elevated temperature is preferable, such as when the hands are visibly soiled, when certain contaminants are involved, or when the individual has Raynaud's phenomenon. However, currently available data suggest that no such benefits exist except, perhaps, in cases of Raynaud's. Additional efforts should be made to more accurately measure and quantify the impact of this behaviour. Although precautions were taken to reduce the effects of social desirability bias on these data, self-report is inherently flawed and behavioural observations would allow for a more accurate estimate of actual handwashing practices. Additional factors, such as the time that water is run to reach the desired temperature, the actual temperature that was reached and throttling of hot vs. cold water could also improve accuracy. Similarly, estimates of the level of emission reductions that could be realistically achieved through updating inaccurate beliefs assume that beliefs about water temperature are causally related to handwashing behaviour. Because the current data are correlational and cross-sectional, causality cannot be established. More research is needed to accurately estimate the level of behaviour change that can be expected by addressing this and other similar behaviours, as well as the most effective methods for educating the public on this issue.

Finally, these estimates are limited to the US, where this study was conducted; however, they have international importance. Parallel studies in other countries would be useful in determining the extent to which consumers associate water temperature with hygiene, as well as the role this perception plays in resource use and resultant GHG emissions. As discussed earlier, it is clear that this perception varies strongly across cultures. For example, ethnographic research has shown that, while cleanliness and hygiene are strongly valued in Japan, hot water is not cognitively connected to cleanliness as it is in Western cultures, and is almost exclusively used for comfort (Wilhite *et al*., 1996). Although this study focused specifically on the issue of water temperature in handwashing behaviour, underlying perceptions of hygiene and water temperature drive a host of related behaviours, including the washing of clothes and dishes. Thus, the role of perceptions and cultural norms surrounding hygiene and water and energy use worldwide has great importance for conserving resources and mitigating climate change.

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Appendix

Explanations of the parameters used in the calculations for water and energy consumption are included in Table A1.

1 Water consumption

To determine the volume of water used for handwashing, the average maximum flow rate of faucets in the US was multiplied by the throttling factor. This figure was then divided by 60 to provide the number of gallons of water used per second of a handwash.

$$\begin{aligned}\text{Liters/second} &= (\textit{Flow Rate}) \times (\textit{Throttle})/60 \\ &= 8.3 \text{ lpm} \times (0.67)/60 \\ &= 0.09 \text{ l/s } (0.03 \text{ gallons/s})\end{aligned} \quad (1)$$

2 Energy required to heat 1 l of water

The energy required to provide a litre of hot water for handwashing was calculated by multiplying the mass of water to be heated in kg (1 l = 1 kg of water) by the change in water temperature that occurs (*Setpoint – Inlet*) and the specific heat of water (Q).

$$\begin{aligned}\text{Required energy (kJ)} &= (\text{Water mass}) \times (\text{Setpoint} - \text{Inlet temp.}) \times Q \\ &= (57°\text{C}-15°\text{C}) \times 4.186 \text{ kJ/kg°C} \\ &= 176 \text{ kJ } (166.6 \text{ Btu}^{8})\end{aligned} \quad (2)$$

3 Fuel required to heat 1 l of water

Actual fuel consumption and GHG emissions were calculated separately for each fuel source. In each equation, the energy required to heat 1 l of water (176 kJ) was multiplied by the proportion of water heaters in the US heated by that specific energy source. This value was then divided by the DOE's 2004 efficiency standard for water heaters powered by that particular fuel source.

$$\begin{aligned}\text{Fuel consumption} = [&(\text{Required energy}) \\ &\times (\text{Proportion of fuel source})]/(\text{Efficiency})\end{aligned} \quad (3)$$

$$\begin{aligned}\text{Electricity} &= (176 \text{ kJ} \times 39\%)/93\% \\ &= 74 \text{ kJ } (70 \text{ Btu}/0.02 \text{ kWh})\end{aligned} \quad (3a)$$

$$\begin{aligned}\text{Natural gas} &= (176 \text{ kJ} \times 54\%)/62\% \\ &= 153 \text{ kJ } (145 \text{ Btu})\end{aligned} \quad (3b)$$

$$\begin{aligned}\text{Fuel oil} &= (176 \text{ kJ} \times 4\%)/59\% \\ &= 12 \text{ kJ } (11 \text{ Btu})\end{aligned} \quad (3c)$$

$$\begin{aligned}\text{Propane} &= (176 \text{ kJ} \times 3\%)/100\% \\ &= 5 \text{ kJ } (5 \text{ Btu})\end{aligned} \quad (3d)$$

$$\text{Total} = 244 \text{ kJ } (231 \text{ Btu})$$

4 GHG emissions

The emission factors used to estimate carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are provided in Table A2. These values were then converted to carbon dioxide equivalents (CO_2eq) based on Intergovernmental Panel on Climate Change estimates for global warming potential (GWP) over a 100-year time horizon. Based on these calculations, the energy used to heat 1 l of hot water results in 0.02 kg of CO_2eq, on average.

[8] We use the ISO conversion factor of 0.9478 British thermal units (Btu) per kilojoule.

Table A1 Explanation of parameters used to calculate water and energy consumption

Parameter	Description	Value	Comment/Source
Flow rate	Faucet flow rate (l/min)	8.3 lpm/2.2 gpm	There are no data on the average maximum flow rate of sink faucets. In 1998, the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (1998) adopted 2.2 gallons per minute (gpm) at 60 pounds per square inch (psi) as the maximum flow rate for all faucets. It is likely that many households and businesses have installed low-flow faucets; however, it is also likely that many faucets exceed this standard. Mayer *et al.* (1999) found that nearly a quarter of showerheads exceeded the maximum flow rate. To be conservative, we adopt the national standard of 2.2 gpm or 8.3 liters per minute (lpm).
Throttle	Degree that faucet that is opened during use	2/3	On most occasions, faucets are used at only a portion of the maximum flow rate. A report prepared for the Department of Housing and Urban Development estimated that, when used for purposes other than filling a container, faucets are throttled at 2/3 of maximum capacity (Brown and Caldwell, 1984).
Inlet temp.	Inlet water temperature	15°C (58°F)	The U.S. Department of Energy (2000) Energy Efficiency Standards for Consumer Products estimates that the nationwide average inlet temperature for water heaters is 58°F or 15°C.
Setpoint	Water heater setpoint	57°C (135°F)	They use 135°F (57°C) as the standard setpoint of a hot water heater when determining energy demand. It is likely that many homes and businesses have followed Department of Energy suggestions to set back their water heaters to 120°F; however, many also exceed the 135°F setpoint. A 1992 study visited a non-representative sample of over 100 homes and found that in 73% of homes, faucet temperatures exceeded 130°F (Sharp and Carter, 1992). To be conservative, and due to a lack of recent data, we adopt the Department of Energy standard setpoint of 135°F (57°C), which is equivalent to 57°C.
Q	Heat capacity of water (specific heat)	4.186 kJ/kg°C	The kilojoules (kJ) of energy required to raise 1 kilogram (kg) of water 1°C
Proportion of fuel source	Proportion of water heated by energy source	Electric: 39% Nat. gas: 54% Fuel oil: 4% Propane: 3%	Based on data provided by the U.S. Energy Information Administration (2005)
Efficiency	Mechanical efficiency	Electric: 93% Nat. gas: 62% Fuel oil: 59% Propane: 100%	To account for energy lost due to mechanical inefficiency, Department of Energy standards for water heater efficiency were included in the analysis. No efficiency standards have been adopted for propane-heated water heaters, therefore, complete efficiency is assumed (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 1998).

Table A2 Emission factors and global warming potential (GWP)

	Electricity[a] (kg/MWh)	Natural gas[b] (kg/MMBtu)	Fuel oil[b] (kg/MMBtu)	Propane[b] (lbs/MMBtu)	GWP[c]
Carbon dioxide (CO_2)	676	53	79	63	1
Methane (CH_4)	0.02	4.75E–03	1.00E–02	4.75E–03	25
Nitrous oxide (N_2O)	0.01	9.50E–05	6.01E–04	9.50E–05	298

[a]Emission factors for electricity production are based on EIA estimates, which include losses incurred in delivering electricity to the point of use. The US average estimate is 0.68 metric tons per megawatt hour (MWh) or 1490 lbs/MWh (U.S. Energy Information Administration, 2007).

[b]CO_2 emissions are based on EIA estimates (U.S. Energy Information Administration, 2007), CH_4 and N_2O estimates are based on calculations from the World Resources Institute (World Resources Institute, 2008).

[c]Provided by the Intergovernmental Panel on Climate Change (2007) report.