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ORIGINAL ARTICLE

The effectiveness of three home products in cleaning and disinfection of *Staphylococcus aureus* and *Escherichia coli* on home environmental surfaces

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Abstract

Aims: The objectives of this study were to investigate three products for: (i) cleaning effectiveness on two common household surfaces, and (ii) disinfection effectiveness against two common bacteria. Products included conventional ('bleach'), environmentally preferable (EP), do-it-yourself (DIY: distilled white vinegar, club soda, tea tree oil), 24-h old DIY, and individual DIY components in dilution.
Methods and Results: For cleaning ceramic, no product was effective (≥85% removal of Hucker's soil), however, DIY performed better than EP and bleach. On stainless, only DIY failed to meet the standard. For disinfection, bleach and EP achieved $\geq 5{\cdot}00\ \log_{10}$ reductions under all conditions. DIY and components were more active against *Escherichia coli* than *Staphylococcus aureus* but only fresh DIY and 50% vinegar achieved $\geq 5{\cdot}00\ \log_{10}$ reductions.
Conclusions: EP is an effective alternative to bleach. DIY may be an adequate alternative for cleaning ceramic and for household use, where complete elimination of micro-organisms is unnecessary; however, it must be freshly prepared each day.
Significance and Impact of the Study: This is the first report of performance of purportedly safer alternatives for both cleaning and disinfection for use in home health care. The EP product and DIY are potential alternatives for some household uses.

Introduction

Cleaning and disinfection of home environmental surfaces are important to prevent the spread of infection. This is particularly critical for more fragile populations such as the very young, the elderly, and those who are immunocompromised. Many potential pathogens, including methicillin-resistant *Staphylococcus aureus*, faecal coliforms, and *Pseudomonas aeruginosa* have been identified on home surfaces (Scott *et al.* 1982, 2009; Rusin *et al.* 1998; Scott 2013) and transmission of pathogens between family members has been documented (Huijsdens *et al.* 2006; Johansson *et al.* 2007; Knox *et al.* 2012). Increasingly, patients are quickly released from the hospital into home settings, often with homecare aides or nurses to assist during their recovery (Bureau of Labor Statistics 2014; Markkanen *et al.* 2014). In a study of more than 7000 patients, Shang *et al.* (2015) reported that during homecare, 3·5% of patients developed severe enough infections to require hospitalization or emergency care. Most homecare aides' visits involve cleaning bathrooms and kitchens as well as wound care, personal hygiene and assistance with other daily living activities. Homecare nurses and aides, as well as patients, need protection from infection, both for their own health and to prevent carrying pathogens from one home to another. With the US population age 65 and older projected to double between 2015 and 2060 (United States Census Bureau 2015) and home health occupations growing rapidly (Bureau of Labor Statistics 2014), home cleaning and disinfection are critical public health concerns. While cleaning and disinfection of environmental surfaces is included in infection prevention guidelines for health care institutions (Sehulster *et al.* 2003; Rutala and Weber 2008; Centers for Disease Control and Prevention 2014), there are no guidelines for home health care.

For home cleaning and disinfection, multiple challenges exist. First, although 'clean' may be generally defined based on the absence of visible soil, infectious pathogens cannot be seen or easily measured in the home. As a result, one cannot readily discern to what extent disinfection is needed or achieved. Second, the resident or cleaner may know nothing about pathogens other than a vague sense of the need for cleanliness and disinfection. They may not know or understand the difference between cleaning and disinfection, including the fact that a surface should be cleaned before it is disinfected. Third, for the average home resident, marketing is the main form of communication about home cleaning. Finally, data show that some cleaning and disinfection products can cause adverse respiratory and dermal health effects, shifting the risk from infection to other unfavourable health effects (Vizcaya *et al.* 2011; Arif and Delclos 2012; Siracusa *et al.* 2013; Markkanen *et al.* 2014).

In the home setting, some individuals will select conventional products such as bleach due to familiarity. It has been shown that some people associate the smell of bleach with cleanliness (Markkanen *et al.* 2014). Bleach (sodium hypochlorite) is readily available, relatively inexpensive and claims a $\geq$ 99·9% ($\geq$3·00 $\log_{10}$) reduction of common household micro-organisms. Others are seeking less hazardous and environmentally preferable (EP) disinfectants as well as cleaners. Many newer commercially available products claim to be 'green', 'organic' or 'natural'. Some of these products make disinfection claims. In addition, so-called 'do-it-yourself' (DIY) recipes for cleaners and disinfectants abound on the internet. For example, a Google search for 'natural disinfectant recipe' returns about 240 000 results. Distilled white vinegar, castile soap, club soda and plant essential oils like tea tree oil (TTO) are common ingredients. Familiarity with the ingredients creates a sense of comfort and safety, and because they are natural products, they may be perceived to be safer than conventional chemicals while still thought to be effective for cleaning and disinfection. As an added benefit, DIY products may be less expensive than commercial cleaners and components may have multiple uses in the home. Some ingredients, such as vinegar and baking soda, may be purchased through food assistance programs, unlike commercial cleaners and disinfectants.

There are limited studies of the disinfection and cleaning effectiveness of other purportedly safer alternatives. For disinfection, Rutala *et al.* (2000) reported that undiluted white distilled vinegar achieved >5·00 $\log_{10}$ (>99·999%) reduction against *Salmonella* spp. and *Ps. aeruginosa*, but <1·00 $\log_{10}$ reduction against *Staph. aureus* and *Escherichia coli* O157:H7 with 30 s contact time in solution. Greatorex *et al.* (2010) showed that 10% malt vinegar was effective in inactivating H1N1 Influenza virus immediately after contact. Jimenez *et al.* (2010) investigated the effectiveness of several commercially available 'green' products on *Salmonella* Typhimurium and *Staph. aureus*, none of which achieved a 5·00 $\log_{10}$ reduction, but one of which achieved a 3·00 $\log_{10}$ reduction. None of these studies addressed cleaning effectiveness.

It is important to characterize the effectiveness of purportedly safer cleaning and disinfection alternatives to inform product choices that will protect vulnerable people, homecare workers and professional cleaners. Because there are no consensus standards for evaluating home cleaning and disinfection, we defined experimental conditions including two surfaces for cleaning and disinfection testing (stainless steel and ceramic), and two bacteria (*Staph. aureus* and *E. coli*). For the purpose of this investigation, effective cleaning is defined as removal of $\geq$85% of soil, a criterion established by the Toxics Use Reduction Institute at the University of Massachusetts Lowell. For disinfection, the Environmental Protection Agency criteria for effectiveness are $\geq$3·00 $\log_{10}$ reduction in micro-organisms for nonfood contact surfaces and a $\geq$ 5·00 $\log_{10}$ reduction for food contact surfaces (Environmental Protection Agency and Office of Pesticide Programs 1976, 1979).

This study is a first step in understanding the effectiveness of purportedly safer cleaners and disinfectants, including DIY options. The objectives of this study were to: (i) evaluate the cleaning effectiveness of three types of common household products: one off-the-shelf conventional product, one EP product, and one DIY formulation, to remove a standard mixture of home soil on two home environmental surface materials, stainless steel and ceramic; and (ii) evaluate the disinfection effectiveness of the three product types to eliminate *Staph. aureus* and *E. coli* from the two surface materials. Most microbiology studies evaluate the disinfection component only, however, cleaning precedes disinfection and can impact disinfection effectiveness and so we evaluated both performance characteristics.

Materials and methods

Products

A conventional commercial product ('bleach') containing 1–5% sodium hypochlorite and 0·1–1% sodium hydroxide (exact composition held as a trade secret) (The Clorox Company, Oakland, CA) and an EP product containing 0·05% thymol (Seventh Generation, Inc, Burlington, VT) were purchased from a local retailer. The DIY recipe consisted of 240 ml club soda (Dr Pepper Snapple Group, Plano, TX), 100 μl TTO (Nature's Bounty, Bohemia, NY), and 240 ml white distilled vinegar, 5% v/v acidity (Hannaford Supermarkets, Scarborough, ME). Prepared DIY was stored at room temperature (24°C) in an HDPE spray bottle. Fresh DIY cleaner, using a new bottle of club soda for each batch, was used within 1 h of preparation. In addition, DIY was allowed to sit in the spray bottle for 24 h at room temperature and tested again. When individual components were tested separately, sterile deionized water was used to replace the other components to maintain the same dilutions.

Cleaning testing method

Cleaning performance testing used the simulated faecal material Hucker's Soil Formulation, that consists of 44·2% distilled water, 13·5% evaporated milk, 8·8% creamy peanut butter, 8·8% salted butter, 8·8% stone ground wheat flour, 8·8% egg yolk, 0·9% printer's ink with boiled linseed oil, 2·7% saline solution 2·7% and 3·5% India ink (Association for the Advancement of Medical Instrumentation Board 2011). Preweighed stainless steel and ceramic coupons were coated with Hucker's soil, dried for 24 h at 24°C and reweighed to determine the amount of soil added. A Gardner Straight Line Washability unit (BYK Gardner, Columbia, MD) was used to standardize cleaning strokes and pressure, and Wypal reinforced paper towels (Kimberly-Clark Corporation, Neenah, WI) were used for cleaning. Three coupons were placed into the Washability unit; a Wypal was attached to the cleaning sled and soaked with 5–7 sprays of product. Each coupon was sprayed 7–10 times with the product. The cleaning unit was run for 20 cycles (~33 s). At the end of the cleaning, coupons were wiped once with a dry paper towel. Final weights were recorded and individual coupon and average percent removals were calculated.

Disinfection testing method

Disinfection testing was modified from the Environmental Protection Agency protocol (Environmental Protection Agency and Office of Pesticide Programs 2013), which provides a surface testing method, as opposed to testing in dilution. *Escherichia coli* 29214 and *Staph. aureus* 6538 were purchased from the American Type Culture Collection (Manassas, VA). Four sterile ceramic or stainless steel coupons (one positive control and three replicate tests) were spotted with 10 μl of overnight growth of *E. coli* or *Staph. aureus* in tryptic soy broth (TSB; Becton Dickinson Co, Sparks, MD). One coupon was left sterile as a negative control. All coupons were dried for 30 min at 37°C; the remainder of the procedure was performed at room temperature (24°C). After drying, the product spray bottle was primed with two full pumps and one full pump (~1 ml) was sprayed onto each coupon. After 30 s, the coupons were transferred to centrifuge tubes containing 15 ml D/E Neutralization broth, mixed on a wrist-action shaker for 5 min, followed by a 30 min incubation at 37°C. Serial dilutions were made in phosphate buffered saline (PBS; Fisher Scientific, Fair Lawn, NJ) and plated in duplicate on tryptic soy agar (TSA: Becton Dickinson Co, Sparks, MD). Colonies were counted after overnight incubation at 37°C. As a number of the colony counts were 0, a Box-Cox transformation was used to avoid taking the log of 0 (Sakia 1992). Average $\log_{10}$ and percent reductions were calculated. Runs were performed in duplicate for a total of six coupons for each set of conditions. Bleach, EP and DIY were tested on both ceramic and stainless steel surfaces for both bacteria. Vinegar, club soda, TTO, and 24-h old DIY were tested against both bacteria on stainless steel only. Neutralization testing was used to confirm the inactivation of the products by D/E Neutralization broth according to standard protocols (Environmental Protection Agency and Office of Pesticide Programs 2014).

Statistical analysis

Statistical analyses were performed to compare the effectiveness of different products. Cleaning effectiveness was evaluated using the average percent reduction in soil weight. Disinfection effectiveness was evaluated using the average $\log_{10}$ reduction in colony counts.

The cleaning data were analysed by analysis of variance (ANOVA) to compare the means of the various groups. For models where the means tested as significantly different ($P < 0{\cdot}05$), a Tukey multiple comparisons method was employed, in a post hoc analysis to determine which individual means were the same or different from each other. The disinfection data were analysed using a mixed model with fixed effects for products and surfaces and a random component for test batch because of the potential for clustering due to the use of the same baseline plate counts for all of the samples from a given batch. The clustering was assumed to have a variance components structure. All analyses were performed in SAS 9.3 (SAS Institute, Inc., Cary, NC).

Results

Cleaning effectiveness

Cleaning effectiveness results for bleach, EP, and DIY are shown in Fig. 1. On stainless steel, bleach and EP met

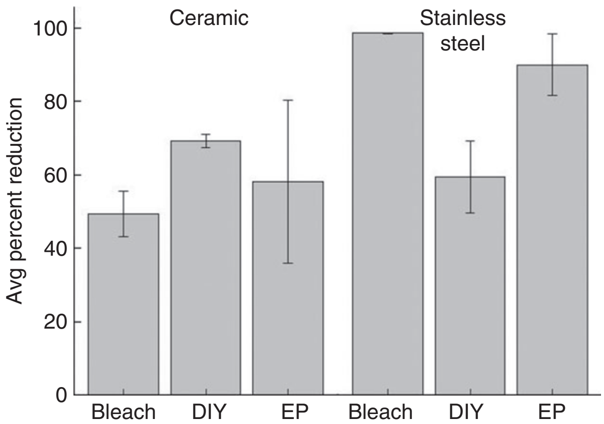

Figure 1 Cleaning effectiveness (average percent soil removed) for environmentally preferable, bleach, and do-it-yourself on ceramic (left) and stainless steel (right). Effective cleaning is defined as ≥85% removal. Average of three replicates. Error bars represent ±1 standard deviation.

the minimum standard of ≥85% removal for cleaning effectiveness (98·69 and 90·04% respectively). DIY achieved a 59·41% reduction, a statistically significant difference between DIY and both bleach and EP ($P < 0{\cdot}001$). On ceramic, none of the products met the minimum standard for cleaning effectiveness. DIY achieved the greatest reduction (69·23%), followed by EP (58·13%) and bleach (49·38%), however, the differences were not statistically significant. ANOVA is shown in Table 1. Cleaning effectiveness for 24-h old DIY and the DIY components is shown in Table 2. None met the minimum standard for effectiveness, and there was no statistically significant difference between them. However, by percent removal all DIY components performed better on ceramic than on stainless, and all DIY components performed better on ceramic than bleach and EP.

Disinfection effectiveness

Disinfection results for bleach, EP, and freshly prepared DIY are shown in Fig. 2. The mixed model for disinfection effectiveness revealed that both bleach and EP were highly effective against both *E. coli* and *Staph. aureus*, achieving a ≥ 5·00 $\log_{10}$ in every replicate on both stainless steel and ceramic surfaces. For *E. coli*, freshly prepared DIY achieved $\log_{10}$ reductions of ≥5·00 for stainless steel and 3·97 for ceramic. For *Staph. aureus*, $\log_{10}$ reductions were 1·90 on stainless and 2·71 on ceramic. The difference between DIY and both bleach and EP was statistically significant ($P < 0{\cdot}001$). For DIY, the difference between *Staph. aureus* and *E. coli* was also statistically significant ($P = 0{\cdot}0028$). The surface (ceramic *vs* stainless steel) did not have an important effect. There was evidence of an interaction between bacteria and product, although it was pronounced only for the DIY data on stainless steel; the effectiveness against *E. coli* was considerably greater than against *Staph. aureus*.

Table 1 ANOVA of cleaning effectiveness for bleach, environmentally preferable, and do-it-yourself

Effect	DF	*F* value	*P*-value
Product	2	1·62	0·2393
Surface	1	21·71	0·0006*
Product-surface	2	11·80	0·0015*

**P*-value of <0·05 is significant.

Table 2 Cleaning effectiveness for 24-h old do-it-yourself (DIY) and each DIY component, in final dilution, on ceramic and stainless steel surfaces*

	Average percent soil removal† (SD)			
	Ceramic		Stainless steel	
Product	% Reduction	SD	% Reduction	SD
24-h old DIY	70·86	7·41	58·89	19·09
Club soda (50%)	72·50	21·14	57·80	4·59
Tea tree oil (0·02%)	69·37	11·72	54·60	8·21
Vinegar (50%)	68·94	6·74	46·67	9·71

*Effective cleaning is defined as ≥85% soil removal.
†Average of three replicates.

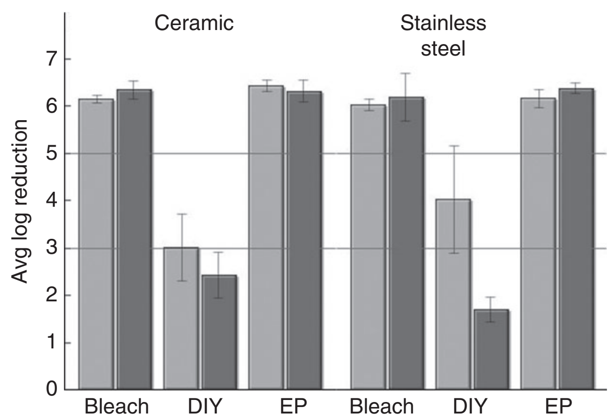

Figure 2 Disinfection effectiveness of bleach, do-it-yourself and environmentally preferable for *Escherichia coli* (light grey) and *Staphylococcus aureus* (dark grey) on ceramic (left) and stainless steel (right) surfaces. Average of six replicates. Error bars represent ±1 standard deviation. Reductions of 3·00 and 5·00 $\log_{10}$ are indicated by solid lines; these represent EPA effectiveness guidelines (see text).

The disinfection effectiveness of 24-h old DIY and the individual DIY components on stainless steel are shown in Table 3. For *E. coli*, 50% vinegar and 0·02% TTO achieved average $\log_{10}$ reductions of ≥5·00 and 3·45

Table 3 Disinfection effectiveness (average $\log_{10}$ reductions) for 24-h old do-it-yourself (DIY) and each DIY component on a stainless steel surface

	Average $\log_{10}$ reduction*			
	Staphylococcus aureus		*Escherichia coli*	
Product	Avg LR	SD	Avg LR	SD
24-h old DIY	0·81	0·60	2·20	2·35
Club soda (50%)	0·03	0·12	1·23	0·13
Tea tree oil (0·02%)	0·24	0·46	3·45	1·87
Vinegar (50%)	2·25	0·21	5·16†	1·08

*Average of six replicates.
†100% reduction of bacteria.

respectively. No other component met either EPA standard for effectiveness.

Discussion

Homecare and health care workers, cleaning professionals, and others with frequent work-related exposure to cleaning and disinfection chemicals are at higher risk for occupational asthma (Vizcaya *et al.* 2011; Arif and Delclos 2012; Siracusa *et al.* 2013; Markkanen *et al.* 2014). Exposure to cleaners and disinfectants during routine housecleaning is less well studied, however, Bello *et al.* (2010) have shown that routine cleaning tasks performed in a controlled environment result in inhalation exposures to airborne volatile organic compounds during and after cleaning. Home use of cleaners and disinfectants in spray form have been linked to asthma in several studies (Zock *et al.* 2001, 2007; Quirce and Barranco 2010; Bédard *et al.* 2014). A recent expert guidance article on cleaning and disinfecting environmental surfaces in health care has identified the lack of information concerning the effectiveness of purportedly safer cleaners and disinfectants as a gap in knowledge (Quinn *et al.* 2015). This study addresses their call for further research to develop an integrated and multidisciplinary approach to address health hazards and effectiveness of cleaning and disinfection in health care.

For this study, we chose surfaces representative of those likely to be found in a household: stainless steel for kitchen appliances and sinks, and ceramic for bathroom sinks and tiles. We tested *Staph. aureus* and *E. coli* as representative Gram-positive and Gram-negative organisms. The selected products are typical of those widely available to consumers. Bleach is a common conventional cleaning and disinfection chemical, well known as a disinfectant, but also well known as a respiratory irritant (Zock *et al.* 2007; Quirce and Barranco 2010). Furthermore, bleach is corrosive and may damage stainless steel and other surfaces over time. The bleach product, we selected is EPA registered and claims to kill 99·9% of household microbes, a 3·00 $\log_{10}$ reduction that meets the EPA standard for nonfood contact surface disinfection. Thymol, the active ingredient in the EP product, has been determined to be generally safe by the EPA although additional inhalational toxicity data are needed (Environmental Protection Agency 2010). Thymol is known to have antibacterial properties against common food-borne pathogens and *Staph. aureus* (Shah *et al.* 2013; Souza *et al.* 2013). The EP product is EPA registered and claims it kills >99·99% of household microbes, a 4·00 $\log_{10}$ reduction, which falls in between the standards for nonfood and food contact surfaces. The DIY recipe represented one that is readily available on the internet and is claimed to have antibacterial activity because of the addition of TTO (Reichert 2008). TTO is popular and found in many products, including cosmetic products such as shampoos, soaps and skin creams, for purported skin benefits and antimicrobial activity. The antimicrobial properties of TTO have been demonstrated *in vitro* against a wide range of organisms (Mickienė *et al.* 2011; Thomsen *et al.* 2011; Kurekci *et al.* 2013). However, TTO is also known to cause adverse effects such as contact dermatitis (Larson and Jacob 2012; Posadzki *et al.* 2012; Rudbäck *et al.* 2012) and endocrine disruption (Henley *et al.* 2007; Nielsen 2008; Henley and Korach 2010). There are no studies of the potential adverse effects of TTO associated specifically with surface cleaning.

Investigating the activity and adverse effects of TTO is complicated by the fact that TTO is a highly complex mixture of terpene hydrocarbons with more than 100 compounds (Scientific Committee on Consumer Products 2008; Lee *et al.* 2013). The complexity of the mixture makes it difficult to determine which constituents and combinations of constituents are associated with the adverse or desired effects. The composition of complex plant essential oils varies with source plants and processing, therefore one source of TTO may be significantly different than another (Scientific Committee on Consumer Products 2008). The International Organization for Standardization (ISO) (2012) regulates the minimum and maximum percentages of the top 15 components of pure TTO for labeling purposes, however, use in cosmetics products is not regulated. Age and storage conditions will also influence the composition of TTO (Scientific Committee on Consumer Products 2008).

For cleaning effectiveness, ceramic appears to be a more difficult surface to clean, with none of the products meeting the minimum standard of ≥85% removal and although the DIY removed the highest percent of soil, there was no statistically significant difference between them. However, on stainless steel, EP and bleach performed significantly better than DIY and DIY components. Under our test conditions, disinfection results exceed the product claims for both bleach and EP, with a $\geq 5{\cdot}00$ $\log_{10}$ reduction for both products against *E. coli* and *Staph. aureus* on stainless steel and ceramic surfaces. There was no variability in either product, all tests resulted in 100% reduction. Freshly prepared DIY was equally effective against *E. coli* on stainless steel, but less effective against *E. coli* on ceramic, although the $3{\cdot}58$ $\log_{10}$ reduction on ceramic exceeds the requirement for nonfood contact surface sanitization. Against *Staph. aureus*, freshly prepared DIY did not achieve a minimum $3{\cdot}00$ $\log_{10}$ reduction on either surface. Overall, there was a statistically significant difference in disinfection performance between the DIY and both commercial products. It is interesting to note that when described in percent reduction rather than $\log_{10}$ reduction, the DIY eliminates >97% of organisms in all cases, with *Staph. aureus* on stainless steel the lowest (97·71%). While not adequate for health care or food service use, from the perspective of general household use, this may be sufficient when coupled with physical removal of soil and organisms through surface wiping.

The approx. 50% loss of disinfection activity when stored at room temperature for 24 h is important information for DIY users (Table 3). It is likely that people who choose to make a DIY recipe for household cleaning and disinfection will not want to make a fresh batch each day of use. DIY recipe users should be informed about the importance of using only freshly prepared solution if disinfection is desired.

When DIY components were tested individually in their final dilutions, only vinegar showed significant antimicrobial activity ($\geq 5{\cdot}00$ $\log_{10}$), and that only against *E. coli*. Although TTO is included in the DIY for disinfection, it only achieved the minimum $3{\cdot}00$ $\log_{10}$ reduction against *E. coli* in the dilution used in this DIY recipe (100 μl in 480 ml, 0·02%); it had very little activity against *Staph. aureus*. The dilution may be too high, or it may be that the particular brand of TTO used for these experiments is less effective than other brands. Future studies should consider higher concentrations of TTO and other plant essential oils. Consumers should be aware that diluted vinegar alone can achieve the same level of disinfection as the full DIY.

A limitation of this study is its use of two bacteria, two testing surfaces, and one soil. Further testing with additional organisms, surfaces, and soils is warranted. Other sources of TTO and other essential oils should be tested and optimal concentrations determined. Future studies should investigate wiping materials (e.g. paper, microfiber, cotton towels) and the impact of wiping on the performance of alternative products.

Evaluating both cleaning and disinfection effectiveness together is useful as many users intend to accomplish both tasks with the same product. From the perspective of performance, the EP product is an effective alternative to the conventional bleach-containing product we tested. The EP product has an odour that users may find to be strong, however, it has no known hazards when used as a surface cleaner and disinfectant. The DIY is not as effective overall, but is made primarily of vinegar and club soda; these common, inexpensive household products can be advantageous for low income households. The steep decline in activity of 24-h old DIY must be taken into consideration as a new batch would need to be prepared each day of use in order to achieve maximum disinfection. This may make this particular recipe less desirable for individual household use. In addition, users may not follow the recipe exactly, potentially altering the effectiveness. While not as effective as a disinfectant compared to the commercial products, the DIY was as effective as the commercial products for cleaning ceramic, but not as effective for cleaning stainless steel. The vinegar in the recipe appears to contribute the most to cleaning effectiveness on ceramic and disinfection on both surfaces. Diluted vinegar alone is an alternative to the full DIY recipe.

When coupled with physical removal of soil and bacteria through wiping, this DIY cleaner could provide effective cleaning and adequate disinfection on some household surfaces. Future studies may elucidate the advantages and drawbacks of these alternatives as we learn more about their effectiveness in actual home settings and potential health hazards. Our study contributes to the body of knowledge for purportedly safer cleaners and disinfectants by providing information that will allow users to make informed choices about the products they use.

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Conflict of Interest

No conflict of interest declared.

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