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RESEARCH ARTICLE

Contamination Is "Good" for Your Memory! Further Evidence for the Adaptive View of Memory

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Abstract

Five studies were designed to provide further evidence of contamination effects in memory. In study 1, participants were told to imagine that either (1) they had been infected in the grasslands of a foreign land (ancestral contamination); (2) they had been infected during a trip in a foreign country (modern contamination); or (3) as tour guide, they had to organize a trip (control condition). Words processed within a contamination scenario (ancestral or modern) were remembered better than words processed in a control scenario. In studies 2 and 3, adults were shown objects that had been touched by someone who had washed his hands after visiting the toilets compared to someone who had not. In a surprise recall test, objects touched by dirty hands were not reliably more recalled than objects touched by clean hands. In study 4, objects were presented with the drawing of a face of a sick or healthy person. The memory performance in the surprise recall test of objects was higher in the sick face context than in the healthy face context. In study 5, faces of people who had signs of contamination or looked healthy were presented next to objects. In study 5a, participants rated their level of perceived discomfort when they imagined touching the objects next to faces (sick vs. healthy) and were then tested for their memory of objects. In study 5b, the same stimuli were presented but here had to be explicitly remembered. In both studies 5a and 5b, source memory was also evaluated. In both studies, participants remembered contaminated objects better than non-contaminated objects and they also remembered contaminated sources better. Taken together, the findings provide further evidence for the adaptive memory view (Nairne 2010), according to which items processed in a context of survival and/or reproduction (here a context of contamination) are remembered better than items processed in non-survival/reproduction contexts.

Keywords Contamination · Behavioral immune system · Adaptative memory

Evolutionary psychologists assume that our ancestors faced a range of evolutionary pressures in the distant past that have sculpted some of the brain's structures and functions (e.g., finding food and drinking water, protecting themselves against predators, finding a mate). Given that memory systems are implemented in the brain, it follows that they should bear the imprints of such deep selection pressures. This view is referred to as the adaptive memory view and it has been championed by James Nairne and coworkers (Nairne 2010; Nairne and Pandeirada 2008, 2010). The aim of the present research was to provide further evidence for this view by testing a prediction that derives from it, namely that contaminated things (or items processed in relation to contamination) are remembered better than non-contaminated things (or items not processed in relation to contamination).

According to the adaptive memory view, long-term memory is tuned to encode and store information related to survival and reproduction better (i.e., fitness-related information) than non-fitness-related information. Indeed, it has been shown that items processed in terms of their survival value are remembered better than items processed in other deep encoding control conditions, such as pleasantness (Nairne et al. 2007; see Bonin and Bugaiska 2014; Kazanas and Altarriba 2015 for reviews). This observation is referred to as the survival

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processing advantage. Our ancestors faced various survival and reproduction-related issues in the distant past, one of which was to pay attention to potential sources of threat. Among the various threats are predators and pathogens. Several studies have shown that dangerous animals are detected faster than non-dangerous animals (e.g., LoBue and DeLoache 2008; Öhman et al. 2001; Penkunas and Coss 2013; Yorzinski et al. 2014). Also, threatening conspecifics are identified better than non-threatening conspecifics (e.g., angry outgroup members: Ackerman et al. 2006; attractive rivals: Maner et al. 2009). Pathogens, which are the focus of our studies, can to some extent be thought as "micro-predators". They are micro-organisms that use our bodies as hosts for their own benefits in terms of fitness without conferring any advantage on us in return. Our memory should therefore be tuned to remember information that has been processed in relation to potential contamination better than information that has not been encoded in relation to contamination (Fernandes et al. 2017; Nairne 2015).

Pathogens are ubiquitous and have been present for millions of years (Murray and Schaller 2016). Throughout human evolutionary history, there have been various infectious life forms (viruses, bacteria, fungi, protozoa, arthropods, and helminths) that can cause infectious diseases. Pathogens therefore exerted strong selection pressures on our remote ancestors (Murray and Schaller 2016). According to certain authors, understanding modern humans requires us to take account of the presence of pathogens (Prokop and Fedor 2013; Thomas et al. 2012). In particular, it is not possible to achieve a better understanding of certain social behaviors—mate preferences, types of sexual behaviors, xenophobia, conservative political attitudes, even music preferences—unless this fact is taken into account (Schaller et al. 2015). Many animal species have evolved immune systems that detect and destroy pathogens that enter the body. However, this comes at a cost since fighting a disease drastically increases the metabolic system (Lochmiller and Deerenberg 2000). By analogy with the biological immune system (Gangstad and Grebe 2014), it has been suggested that humans are equipped with a *behavioral immune system* (Schaller and Park 2011; Schaller et al. 2015), which is a new concept. This system corresponds to a set of mechanisms whose function is to minimize the risk of infection. To avoid being infected, people deploy reactive behaviors such as avoiding contact with individuals who seem to be bearers of a potential disease (Ryan et al. 2012). For instance, they avoid touching an object that they think has been touched by an individual who looks feverish (for a brief review on anti-parasite behaviors in animals, see Prokop and Fedor 2013). The behavioral immune system consists of different (cognitive and affective) mechanisms, including a detection mechanism that identifies symptoms of infection (e.g., sneezing) or pseudo-infection (e.g., facial blemishes). More precisely, to quote Schaller and Duncan (2007): "This system is comprised of a set of mechanisms that allow individuals to detect the potential presence of parasites in the objects and individuals around them, and to engage in behaviors that prevent contact with those objects and individuals." (p 295). Disgust is an emotional response and a key component of the behavioral immune system (Schaller and Park 2011). It can be elicited by specific visual and/or olfactory cues (e.g., rotten food, feces, blood, vomit). Disgust is assumed to be related to features that more generally connote disease (Curtis et al. 2004; Oaten et al. 2009).

Several studies have provided evidence of the availability of such a system in humans. To give a few examples, it has been shown that people who are temporarily made to feel threatened by infectious diseases, for instance by watching slideshows, exhibit more xenophobic attitudes than people who are sensitized to other kinds of life-threatening dangers (Faulkner et al. 2004). This is because "foreign" people tend to be stereotypically associated with a variety of dangers, one of which is the threat of infection. Importantly, the behavioral immune system is linked to the biological system: the mere perception of other people's symptoms can cause the biological system to generate an aggressive immune response (e.g., white blood cells produce higher quantities of proinflammatory cytokine interleukin-6) (Schaller et al. 2010). Conversely, activation of the biological system as a result of recent sickness leads to the activation of the behavioral immune system (Miller and Maner 2011).

In the present studies, we aimed to explore further the relationship between contamination and long-term memory. Remembering items that are contaminated is useful for survival, and thus adaptive, since it makes it possible to avoid these items when they are encountered again in a future situation (e.g., objects touched by someone who is sick). However, this component of the behavioral immune system has not as yet been thoroughly investigated. Related to this, although the number of studies favoring the adaptive view of memory has grown steadily in recent years, the most prominent lines of evidence in favor of this view are at present the survival processing advantage described above and, albeit to a lesser extent, animacy effects.[1] As a result, very few studies have shown that things processed in relation to contamination are remembered better than healthy (non-contaminated) things.

Nairne and Pandeirada (2010) examined the memory performance of adults (in a surprise free recall test) after they had

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[1] Animacy effects correspond to the observation that animates are remembered better than inanimates and are accounted for by assuming that the former generally have a stronger fitness value than the latter since animates can be prey, predators, friends or foes, or potential sexual partners (Bonin, Gelin, & Bugaiska, 2014; Bonin, Gelin, Laroche, Méot, & Bugaiska, 2015; Gelin, Bugaïska, Méot, & Bonin, 2017; Nairne, VanArsdall, Pandeirada, Cogdill, & LeBreton, 2013; Popp and Serra 2016; VanArsdall, Nairne, Pandeirada, & Blunt, 2013).

rated words for their relevance in two survival scenarios that tapped the recurrent adaptive problem faced by our ancestors of treating a dangerous infection. One scenario was an ancestral scenario in which participants had to imagine that they had been hurt and might be developing a dangerous infection. They had to search for and find relevant medicinal plants to ensure their survival. In the modern scenario, the imagined situation was the same except that the expression "medicinal plants" was replaced by "antibiotics". Pleasantness was used as a control condition for both scenarios. In both scenarios (but more reliably so in the ancestral scenario), words that were processed in relation to the survival problem of potential contamination were recalled better than words processed for their pleasantness. More recently, Fernandes et al. (2017) reported a series of studies in which people were presented with pictures of objects. Each object (e.g., *a hat*) was accompanied by a statement or by a face of somebody indicating whether it had been touched by a healthy person (e.g., *person with a straight nose; face of someone looking healthy*) or by someone who had been infected, for instance by a virus (e.g., *person with a constant cough; face of someone ill*). The participants were told to explicitly learn these object-sentence/face associations for an immediate memory test. This test was used to ensure that the object-statement associations were established. In a final incidental memory test, the names of the contaminated objects were recalled better than those of the non-contaminated objects.

Cues that are perceived as indicating diseases are likely to trigger disgust (Ryan et al. 2012) and there is evidence that things that elicit disgust are memorized better than things that do not look disgusting. For instance, Chapman et al. (2013) found that disgusting pictures were remembered better than fear-inducing and neutral pictures when important dimensions were controlled for (arousal, valence). In addition, disgusting behaviors are well-remembered (Bell and Buchner 2010). Similarly, Prokop et al. (2014) tested whether knowledge of disgusting stimuli (parasites) is remembered better than knowledge of non-disgusting, non-life-threatening stimuli (hormones). It turned out that knowledge of parasites tested immediately after the experiment was significantly better than knowledge of hormones. Thus, contamination-relevant information is also retained better than contamination-irrelevant information. However, one issue is the extent to which disgust is involved and activates memory mechanisms when attention is captured by contamination cues (Al-Shawaf et al. 2015). According to Fernandes et al. (2017), disgust is one candidate mechanism (but not the only one) underpinning the contamination memory advantage.

Although important and interesting, the findings reported above need to be complemented by other studies in order to provide further evidence that our memory has evolved to retain information that is relevant for survival issues. More particularly, the goal of our studies was to show that, given our ancestors' recurring problem of avoiding contamination, we should be able to better remember items that potentially threaten our health. The first study was a quasi-replication of Nairne and Pandeirada's (2010) study 2. However, we added an important condition that was missing in their study, namely processing words in a modern contamination situation that created no explicit link to a survival situation. Likewise, in this modern context, the contamination factor was more developed and tapped less into survival processing per se. The precise methodological differences between Nairne and Pandeirada's (2010) study and the current study 1 are given in the "Method" section.

In studies 2–5, we examined the recall of information related to contamination in non-survival contexts based on the experimental design used by Fernandes et al. (2017) and tested further whether objects touched by people who are perceived as being the bearers of potential infections are memorized better than objects touched by people who are perceived as healthy. The general goal was to investigate different situations where there is a potential for contamination, thus further testing the adaptive memory view (Nairne 2010, 2013, 2015; Nairne and Pandeirada 2008). However, one important issue in the domain of adaptive memory relating to contamination that was not addressed by Fernandes et al. (2017), and which indeed represents a genuine contribution of the present research work, is whether *a single cue of potential contamination* is enough to boost memory. From an evolutionary perspective, the fact that a single cue of potential contamination is able to activate this memory tuning appears adaptive. This important issue was addressed in studies 2–4. In studies 2 and 3, participants had to remember words denoting objects that had been touched by someone who had washed his hands after visiting the toilets compared to someone who had not. In study 4, participants had to remember objects that were presented with the drawing of a face of either a sick or a healthy person. The same faces were used throughout the experiment. Studies 5a and 5b are thought of as quasi-replications and extensions of Fernandes et al. (2017) study 2 and the precise methodological differences between our studies and theirs will be described later in the corresponding "Method" sections. In studies 5a and 5b, as in Fernandes et al. (2017) work, participants were presented with faces of real people who either did or did not bear signs of contamination and each face was accompanied by an object. In study 5a, an incidental encoding procedure was used: participants had to rate their level of perceived discomfort when they imagined touching and interacting with objects placed next to faces of real people with or without signs of infections. In study 5b, the same stimuli were presented and had to be remembered. Importantly, in study 5b, we also took into account individual measures of disgust and perceived vulnerability to disease.

Study 1: Quasi-replication of Nairne and Pandeirada's (2010) Study 2

Method

Participants Ninety-nine students (79 females; mean age 20.36 years) at the University of Bourgogne Franche-Comté participated in the study and were tested individually. The participants were all native speakers of French. None were taking medication known to affect the central nervous system. The studies reported in the present article were performed in a pedagogical context, in which students, in exchange for course credits, have to participate in a non-invasive laboratory experiment. Informed written consent was obtained from all the participants before each experiment. The sample size was planned to be comparable to that used in the Gelin et al. (2017) study 3 in which a significant difference was observed between a tour guide scenario and a grassland survival scenario (an explicit learning condition was also present). It is important to note that a post hoc analysis performed on the basis of the contrast test reported in this study revealed a high power: only 13 participants would be sufficient to achieve power of .80 to detect an effect at the .05 significance level.

Stimuli The same word stimuli as had been used in a previous study conducted to examine animacy effects were used (Gelin et al. 2017). Whereas Nairne and Pandeirada (2010) used 32 unrelated concrete nouns, the words used here consisted of 28 French (animate or inanimate) nouns that were selected from Snodgrass and Vanderwart's (1980) and Bonin et al.'s (2003b) databases.

Design The study used a between-subject design with type of scenario as the independent variable. In Nairne and Pandeirada (2010), a mixed design was used with type of scenario (ancestral versus modern) being manipulated between-subjects and the rating task (survival scenario versus pleasantness) manipulated within-subjects.

Procedure The participants were randomly assigned to one of the three encoding conditions (survival contamination, modern-context contamination, tour guide [$n = 33$ in each condition]). The instructions used in the survival contamination condition were similar (not identical) to those used in Nairne and Pandeirada's (2010) study 2. For instance, they were more threatening (the words *death* and *paralyzed* were used, see below), they put a greater emphasis on the risk of contamination (by using the words virus and bacteria in addition to the word infection), while certain expressions (e.g., *You will need to search for and find relevant medicinal plants*; *antibiotics to ensure your survival*) were also removed from the original instructions.

> *Survival contamination condition*: "In this task, we would like you to imagine that you are stranded in the grasslands of a foreign land, without any survival equipment. You have recently been hurt and a dangerous infection might be developing. It is all the more urgent to heal this wound because where you are, there are bacteria and virulent viruses that can cause terrible harm if an infection develops. Indeed, you may be left paralyzed, or worse, die. You must therefore do everything you can to avoid becoming contaminated. We will present you with a list of words and want you to rate the relevance of each word in the situation described. Some of the words may be relevant and others not, it's up to you to decide. You must use a rating scale of 1 (totally irrelevant) to 5 (extremely relevant)."

In the modern-context contamination condition, the participants were told that they had to imagine they were taking part in an organized trip in a foreign country. They were then given exactly the same instructions as in the survival contamination conditions.

> *Modern-context contamination*: "In this task, we would like you to imagine that you are participating in an organized trip in a foreign country. You have recently been hurt and a dangerous infection might be developing. It is all the more urgent to heal this wound because where you are, there are bacteria and virulent viruses that can cause terrible harm if an infection develops. Indeed, you may be left paralyzed, or worse, die. You must therefore do everything you can to avoid becoming contaminated. We will present you with a list of words and want you to rate the relevance of each word in the situation described. Some of the words may be relevant and others not, it's up to you to decide. You must use a rating scale of 1 (totally irrelevant) to 5 (extremely relevant)."

In the *tour guide condition*, the instructions were the same as in Gelin et al.'s (2017) study 3:

> "In this task, imagine that you are working in a travel agency as tour guide. Over the next few months, you'll need to organize a trip for a group of people: find accommodation, arrange meals and attend to administrative procedures (e.g., insurance, reservations). We would like you to rate how relevant each word would be for you in this situation. Some of the words may be relevant and others may not be—it's up to you to decide."

In each encoding condition, the words were randomly presented individually in the center of the screen until the participant responded (there were no practice trials). Thus, unlike Nairne and Pandeirada (2010) who used a fixed presentation of 5 s, the presentation time of the words here was determined by the participants. The participants indicated their responses by pressing a key (labeled 1 through 5 on the keyboard) corresponding to their choice. The test phase was administered after a 5-min retention interval. During this period, the participants had to perform two interference tasks: the ‘X-O’ letter-comparison task (Salthouse et al. 1997) and the ‘plus-minus’ task from Jersild (1927) and Spector and Biederman (1976). In Nairne and Pandeirada’s (2010) study, the interference task was a digit identification task that lasted for about 2 min. At recall, the participants had 5 min (10 min in Nairne and Pandeirada’s 2010 study) to write down the previously presented words in any order they liked.

Results and Discussion of Study 1

Encoding times did not differ significantly among the different scenarios, $F(2, 96) = 1.96$, $p = .147$, $\eta^2_p = .039$ (survival contamination: $M = 2288$ ms, $SD = 560$; modern contamination: $M = 2095$, $SD = 444$; tour guide: $M = 2310$, $SD = 441$). Also, the rating scores were not significantly different between the three encoding conditions (survival contamination: $M = 2.09$, $SD = .50$; modern contamination: $M = 1.97$, $SD = .71$; tour guide: $M = 2.26$, $SD = .48$), $F(2, 96) = 1.97$, $p = .145$, $\eta^2_p = .039$.

Correct recall rates were significantly different between the scenarios, $F(2, 96) = 4.74$, $p = .011$, $\eta^2_p = .09$. The survival contamination ($M = .51$, $SD = .11$) and modern contamination ($M = .48$, $SD = .13$) conditions did not differ reliably, $t(96) = .84$, $p = .405$, $d = .206$.[2] However, the survival contamination and the modern contamination conditions both differed significantly from the tour guide condition ($M = .42$, $SD = .12$), $t(96) = 2.98$, $p = .004$, $d = .735$ and $t(96) = 2.15$, $p = .034$, $d = .529$, respectively. Finally, the number of extralist intrusions was not significantly different among the different encoding conditions, $F(2, 96) = 2.09$, $p = .13$, $\eta^2_p = .042$: survival contamination ($M = 0.48$, $SD = 0.87$), modern contamination ($M = 1.09$, $SD = 1.63$), and tour guide scenarios ($M = 0.82$, $SD = 0.98$).

Thus, in this study, we replicated the finding initially reported by Nairne and Pandeirada (2010) that processing items in relation to survival contamination issues leads to better memory than processing the same items in relation to non-survival issues. Given that we also found that items processed in a modern contamination scenario were recalled better than in a control scenario, it cannot be argued that the memory effect observed in the present study was due to the general survival situation. It remains possible, however, that the pattern of recall rates is due to the fact that both the ancestral and modern contamination scenarios were more interesting, familiar, emotionally arousing, or image-arousing than the tour guide scenario. In order to evaluate these possibilities, we conducted a follow-up study in which we asked individuals who had not participated in the study to rate the three scenarios on these dimensions. Forty-two adults (35 females; mean age 19.6 years), who had not participated in study 1, were recruited via different psychology student Facebook groups. The questionnaire was created using Limesurvey and was completed online by the participants. The scenarios were randomly presented to the participants. In addition, different random orders were created to present the different dimensions for rating. However, to avoid any confusion, the different questions, with the Likert scale below them, were presented in the same order across the three scenarios for any given participant. The questionnaires were self-paced and took about 5 min to complete.

Table 1 shows the means and standard deviations of the ratings of the scenarios.

We analyzed each dimension using separate ANOVAs with the Scenario as a between-participants factor.

Even though the scenarios differed significantly on the familiarity dimension, $F(2, 82) = 7.88$, $p < .001$, $\eta^2_p = .161$, the survival contamination scenario was judged to be significantly less familiar than the other two scenarios (modern contamination: $t(41) = -2.22$, $p = .032$, $d = -.316$; tour guide: $t(41) = -3.97$, $p < .001$, $d = -.672$), while these latter two scenarios did not reliably differ, $t(41) = -1.86$, $p = .07$, $d = -.338$. Moreover, the different scenarios did not differ significantly on any of the other rated dimensions: interest: $F(2, 82) = 2.73$, $p = .071$, $\eta^2_p = .062$; imagery: $F(2, 82) = 1.41$, $p = .249$, $\eta^2_p = .033$; emotional arousal: $F(2, 82) = .47$, $p = .629$, $\eta^2_p = .011$.

The hypothesis that contamination was a recurring selective pressure in the distant past, and that our memory systems have become tuned to better retain this type of information, is supported by the present findings. It is important to note that the effect on recall rates was obtained with only *one* survival problem—contamination—described in the (ancestral) survival situation, in contrast to the original grassland survival scenario used by Nairne et al. (2007) in which there were *many* survival problems, namely finding food, drinking water, and protection from predators. Given that it has been argued that the survival processing advantage could be due to the *number* of survival problems that people have to deal with (Kroneisen and Erdfelder 2011), this is an important finding. Nevertheless, it is worth remembering that in Nairne and Pandeirada’s (2010) study 1, a survival memory advantage was obtained with only one survival problem included in the survival scenario, namely protection from predators.

In the following studies, we examined the recall of information related to contamination in non-survival contexts based on the experimental design used by Fernandes et al. (2017). It has been found that people find objects touched

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[2] d was computed as the ratio of the difference between the observed means over the square root of the residual mean square.

Table 1 Mean ratings (and standard deviations) for familiarity, interest, imagery, and emotional arousal as a function of type of scenario (study 1)

	Ancestral contamination	Modern contamination	Tour guide
Familiarity	1.52 (0.83)	1.81 (0.97)	2.14 (1.00)
Interest	3.40 (1.06)	3.33 (1.05)	2.93 (1.13)
Imagery	3.57 (0.97)	3.71 (0.99)	3.83 (0.85)
Arousal	2.88 (1.17)	2.76 (1.30)	2.64 (1.14)

by sick individuals or by individuals who are healthy but are the bearers of cues that evoke disease more disgusting and that they are more reluctant to use them with their hands or other body parts (e.g., birthmark, Ryan et al. 2012). These findings can be explained if we assume that people consider that contaminating properties are transferred from people to objects by mere contact (Rozin et al. 1986). Indeed, it has been observed that certain objects are full of bacteria, for instance objects found in working areas such as chairs or phones (Hewitt et al. 2012) and that it is possible to become contaminated by touching these objects. By a law of contagion, some objects can be envisioned as being contaminated if people imagine some kind of transfer of pathogens from objects to objects (for examples, see the studies by Argo et al. 2006, or Morales and Fitzsimons 2007), or from people to objects even though the objects are not for real contaminated. For example, seeing the photographed face of someone with a leprosy next to a photograph of a glass can suggest the idea that the glass is itself contaminated, even though this situation is purely fictional and there has been no real contact between the two items. However, the behavioral immune system reacts as if the situation were real and a source of risk. Consequently, in such situations, people can react adversely and memory for "contaminated objects" may be boosted. This is precisely the hypothesis that we assessed in the following studies. As indicated above, although there is some evidence in its support, this is very limited, and to our knowledge, comes from only a single research team. Thus, as emphasized by Roediger (2012), replications of such studies are needed in order to establish the robustness of contamination effects in memory (as well as their boundary conditions). However, beyond the purposes of mere replication, our goal was also to test other contamination contexts in order to evaluate the extent to which the memory component of the behavioral immune system is triggered. Also as stated earlier, in studies 2–4, since this had not been tested before but is important from an evolutionary point of view, we tested whether *a single cue of contamination* was sufficient to boost memory of contaminated things.

In the next study, we explored the impact on memory of a new contamination context, namely when hands are in contact with potential sources of contamination in an everyday situation where there are many pathogens, namely toilets. The participants were presented with a list of pictures of objects that had been touched by someone who had washed his hands after visiting the toilets compared to someone who had not, i.e., whose hands were dirty. They were then given a surprise memory test at the end of the list presentation. They had to write down the object names they remembered in any order they liked. According to Fernandes et al. (2017), when items are placed in a fitness-relevant context, in this case a contamination threat, a memory boost should be observed. We therefore explored this contamination context in relation to memory.

Study 2: Memory for Objects Touched by Dirty Versus Clean Hands

Method

Participants Forty-six students (38 females; mean age 19.65 years) at the University of Bourgogne Franche-Comté participated and were tested individually. As in the previous study, all the participants were native speakers of French and were given course credits for their participation. None were taking medication known to affect the central nervous system. In this study, as well as in the following studies, the number of participants was chosen in order to be comparable with that employed in Fernandes et al.'s (2017) study 2 in which a similar design was used. With a standardized mean change estimated at .41 in the recall test of Fernandes et al.'s (2017) study 2, an a priori power analysis revealed that with such an effect size, 46 participants lead to a power of .78 in a bilateral test (.86 in an unilateral test) at the alpha level of .05. It is worth remembering that the direction of the contamination effect is predicted, with the result that a one-tailed test should be appropriate here (see, for instance, Roelofs and Piai 2017 for this type of application).

Stimuli Thirty colorized pictures of objects were selected from the Rossion and Pourtois (2004) database. The 30 pictures were divided into two lists of 15 pictures for the "hands" variable: dirty vs. cleaned hands.

As can be seen from Table 2, the two lists (1 vs. 2) were matched for the *surface variables* of number of letters, number of phonemes, syllables, and bigram frequency; the *lexical variables* of book and subtitle frequency, age of acquisition, number of orthographic neighbors; and the *semantic variables* of conceptual familiarity, imageability, concreteness, and emotional valence. The pictures in both lists also had high name agreement scores.

Table 2 Statistical characteristics (mean (M) and standard deviations (SD)) of the control variables in study 2 for the two lists of pictures

	List 1		List 2	
	M	SD	M	SD
Number of letters[a]	5.87	1.67	6.06	1.29
Number of phonemes[a]	4.2	1.27	4.53	1.26
Number of syllables[a]	1.6	.61	1.67	.70
Bigram frequency[a]	8329	3527	6501	4281
Book frequency[a]	24.66	24.79	28.26	37.59
Subtitle frequency[a]	14.17	11.34	22.06	30.31
Age-of-acquisition[b]	1.92	.43	1.99	.49
Number of orthographic neighbors[a]	5.06	4.46	3.33	3.82
Conceptual familiarity[b]	3.05	1.04	2.83	.59
Imageability[c]	4.66	.23	4.57	.28
Concreteness[c]	4.83	.07	4.82	.17
Emotional valence[c]	3.3	.46	3.29	.60
Name agreement scores (%)[b]	97.33	6.32	91.07	16.05

[a] Values taken from Lexique (www.lexique.org; New et al. 2004)

[b] All the scales are 5-point scales. The values were obtained from Bonin et al. (2003b), and from Alario and Ferrand (1999)

[c] All the scales are 5-point scales. The values were obtained from Bonin et al. (2003a)

Apparatus An Apple computer running the Psyscope v.1.2.5 software (Cohen et al. 1993) was used. The computer controlled the presentation of the stimuli.

Design A within-subject design was used with type of hands (dirty vs. clean) as the independent variable.

Procedure The participants started by reading an extract from a French popular science magazine "Science et Univers (edition 24, 2017)" (about 10 lines) which explained that the hands are vectors for large number of pathogens. They then read a story telling them that two friends went to a restaurant for lunch. After paying the bill, they both visited the restaurant's toilets. One friend (e.g., Paul) washed his hands before leaving, whereas the other did not (e.g., Marc). The participants were then told that they would be presented with a list of pictures, all of which corresponded to objects, and they had to pay attention to the association between the picture and a symbol (a small colored cloud) below it. Each picture and its corresponding symbol were presented on the screen for 5 s. The cloud was colorized either in blue or in brown. The brown cloud was used to indicate that the objects referred to by the pictures had been touched by the dirty hands of one of the two friends and the blue cloud indicated that the objects had been touched by the friend who had washed his hands (clean hands). Across participants, the surnames of the two friends—Paul and Marc—were counterbalanced across the two picture sets. In addition, the two lists of pictures were counterbalanced across the two "hand conditions" (clean vs. dirty). After this encoding phase, the participants had to perform the same two interference tasks as described in study 1 for 3 min. Finally, they were given a surprise free recall task that lasted 5 min. They had to write down all the previously presented words they could remember in any order they liked.

Results and Discussion of Study 2

Dirty-hand items were not recalled significantly better ($M = .44$, $SD = .16$) than clean-hand items ($M = .42$, $SD = .14$), $t(45) = 1.25$, $p = .22$, $d = .16$.[3] The number of extralist intrusions was low ($M = .8$, $SD = 1.13$).

In contrast to Fernandes et al.'s (2017) findings obtained in a slightly different situation, we did not find that objects reported to have been touched by dirty hands were memorized better than objects reported to have been touched by clean hands. We therefore failed to find a contamination effect in this study.

Although people know objectively that one can be contaminated by people who act unhygienically by not washing their hands (Curtis and Cairncross 2003; Rabie and Curtis 2006), failure to wash one's hands after visiting the toilet might not immediately and reliably indicate a danger of being contaminated since there is a priori no visible sign of infection. Also, given that there are no visible signs of infection, these do not induce any level of disgust. In line with this suggestion, certain studies (Porzig-Drummond et al. 2009; Judah et al. 2009) have shown that hand-hygiene interventions are more effective when they trigger disgust, for instance by showing contaminating agents (e.g., a video showing a sneezing scene with an image of nasal secretions on the person's hand; a poster picturing a long bread roll containing feces as a filling). In our study, dirty hands were indicated by a symbol and this symbol was not in itself disgusting. Moreover, in the scenario, it was only indicated that one of the two friends did not wash his hands. However, the participants did not see any hands and these had to be imagined. It is possible that most of the participants did not imagine the hands of the protagonist who did not wash his hands with disgust-eliciting stimuli on them (e.g., trace of urine). Thus, it might be thought that for a contamination effect in memory to occur, signs of infection have to be visible and the emotion of disgust must be triggered in some way. However, Fernandes et al. (2017) have shown that a simple descriptor is enough for a contamination effect to occur in memory (e.g., a verbal statement such as *person with a high fever*). Before further discussing the findings of study 2, we need to address the possibility that the experimental setting that we used did not allow the participants to effectively associate the condition (contamination/non-contamination) with

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[3] d was computed as the ratio of the difference between the observed means over the square root of the mean of the variances.

the objects. As a result, we decided to design a quasi-replication of study 2 that took account of the concerns indicated above.

Study 3: Quasi-replication of Study 2

In this study, we first changed the contamination situation in order to make it easier to imagine. We no longer told the participants about two friends who went to a restaurant using two different surnames to refer to them. We merely referred to two different people, one who washed his hands after visiting the toilets and another who did not. The participants were told they would see a series of objects, some of which touched by someone who washed his hands and others that had been touched by the other person who did not wash his hands. Similarly, the associations between the conditions (contamination vs. non-contamination) and the objects were easier to process. Second, since we conjectured that most of the participants did not imagine the hands of the protagonist who did not wash his hands with disgust-eliciting stimuli on them (e.g., trace of urine), we added a drawing of a hand next to each object. One hand was drawn in such a way that there were yellow and brown spots (see Fig. 1 in the Supplemental Material) symbolizing traces of urines and feces—the dirty hand—whereas the other hand consisted of light and dark blue spots indicating that the hands had been cleaned (Fig. 1). Finally, we no longer asked the participants to start the experiment by reading an extract from a popular French science magazine explaining that the hands are vectors for large numbers of pathogens because it is possible that this might have primed a general state of disgust influencing the encoding of both "dirty" and "clean" objects.

Method

Participants Forty-eight students (43 females; mean age: 18.98 years) at the University of Bourgogne Franche-Comté participated and were tested individually. The participants were all native speakers of French and were given course credits for their participation. None were taking medication known to affect the central nervous system.

Stimuli We used the same colorized pictures of objects as used in study 2. There were two drawings of hands. The dirty hand was drawn in such a way that there were yellow and brown spots symbolizing traces of urines and feces (see Fig. 1 in the Supplemental Material). The other hand consisted of light and dark blue spots to indicate that the hands had been cleaned.

Apparatus and Design These were the same as in study 2.

Procedure The same contamination situation was used as in study 2 but in a greatly simplified form. The participants were told they would see a series of objects some of which had been touched by the person who washed his hands, while the others had been touched by the other person who did not wash his hands.

Each object was presented with an adjacent drawing of a hand that was either "dirty" (yellow and brown spots to indicate traces of urine and feces, respectively) or "clean" (blue spots and water drops to indicate cleanliness) (see Fig. 1 in the Supplemental Material). As in study 2, each picture and its corresponding hand were presented on the screen for 5 s. After this encoding phase, the participants had to perform the same two interference tasks as described in study 1 for 3 min and were then given a surprise free recall task for 5 min. They had to write down all the previously presented words corresponding to the pictured objects that they could remember in any order they liked.

Results and Discussion of Study 3

As found in study 2, dirty-hand items were not recalled significantly better ($M = .40$, $SD = .17$) than clean-hand items ($M = .38$, $SD = .16$), $t(47) = 0.72$, $p = .47$, $d = .13$. The number of extralist intrusions was low ($M = .875$, $SD = .94$).

With an experimental setting that permitted participants to associate the condition (contamination/non-contamination) more effectively with the objects, we did not find that contaminated objects were remembered better than non-contaminated objects. Thus, study 3 replicates the findings of study 2. It is worth stressing that we did not find a contamination effect in memory even though we used a drawing of a dirty hand depicting signs of contamination (e.g., traces of urine).[4] It therefore appears that signs of contamination do not automatically lead to contamination effects in memory. This is an important finding which suggests that a context of contamination is not in itself sufficient to trigger a memory boost for contaminated things. It is possible that the situation described in studies 2 and 3 was not sufficiently threatening and, indeed, it has been shown that the information has to be threatening, that it is to say associated with negative consequences for other people, if it is to be particularly well-remembered (Bell and Buchner 2012).

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[4] Importantly, we checked in an independent group of 40 participants (37 females; mean age: 21.58 years) that the two hands were categorized as we intended (the "dirty hand" categorized as dirty vs. "clean hand" as clean). The participants were shown the two hands on a sheet of paper (half were shown the "dirty hand" on the left and the "dirty hand" hand on the right and the reverse for the other half) and they had to indicate which hand was the dirty hand and which was the clean hand. It turned out that only one participant did not categorize the hands as we intended. Thus, fortunately, our a priori classification of the drawings of the two hands accords with the judgments of independent participants not involved in Study 3.

It could also be argued that because the participants were told that the objects had been touched by dirty hands (versus clean hands) but were not given to understand that they would have to imagine touching the objects afterwards, they themselves were not directly concerned with a potential infection. In the following experiments, we took this issue into account: the participants were directly involved since they had to imagine touching the contaminated objects. Finally, in all Fernandes et al.'s (2017) studies, the participants were presented with different types of contamination cues either verbally (e.g., person with a high fever; person with a rash on the skin) or by means of faces depicting different types of affections (e.g., conjunctivitis, eczema, herpes). If we assume that disgust is a key factor boosting memory in a contamination context (Fernandes et al. 2017), then disgust is more likely to be activated to some level when different contamination cues are used during the encoding phase. However, it would not be adaptive if contamination boosts memory *only* when participants are presented with *several forms of contamination* and not when they are presented with *only one type of affection* throughout the encoding phase. Thus, from an evolutionary perspective, a single cue of potential contamination should be enough to activate this "memory tuning". This issue was not addressed by Fernandes et al. (2017), but it represents an important issue in the domain of adaptive memory related to contamination. Thus, in study 4, as was the case in studies 1 and 2, the participants had to remember objects that were presented with only one type of contamination cue. Likewise, we used the drawing of a face of someone with a respiratory illness such as influenza (see Fig. 2 in the Supplemental Material for an illustration of the sick face used in our study). A similar type of drawing was used to depict the healthy face (Fig. 2). The depicted faces were presented as those of two brothers, one of whom was ill and the other of whom was healthy (see Procedure for the detail of the encoding scenario).

Study 4. Memorizing Objects Touched by Healthy Versus Contaminated Drawing Faces

The experimental design of study 4 was similar to studies 2 and 3, except that we used two drawing faces. Moreover, (1) the participants in the contamination condition were explicitly told that they would have to touch the objects, (2) signs of infections were clearly visible throughout the encoding phase (as in study 3) since the different objects were presented next to the sick face in the contamination condition.

Method

Participants There were 47 adults (39 females; mean age 19.66 years), all students at the University of Bourgogne Franche-Comté who were tested individually. As in the previous studies, they were all native speakers of French and were given course credits for their participation. None were taking medication known to affect the central nervous system.

Stimuli We used the same stimuli as described in study 2. A professional artist drew a healthy and a sick face based on one and the same character. Using Photoshop software, we created two other faces from this character in order to obtain the brothers' faces with different hair colors as well as with different pull-over colors (see Fig. 2 in the Supplemental Material).

Apparatus We used the same apparatus as described in study 2 to present the stimuli.

Design A within-subject design was used with type of faces (sick vs. healthy) as the independent variable.

Procedure The participants were told to imagine visiting two brothers in order to help them prepare a birthday party. Inside the apartment where the two brothers were, there were different objects belonging to one or the other brother. They then learned that one of the two brothers (named Paul or Marc depending on the counterbalanced version in which the participants were involved) had a serious cold: his nose was running and he was coughing of lot, whereas the other brother (Marc vs. Paul) was in good health. In order to organize the party, the participants would have to touch different objects. The objects in question would be shown to them together with the face corresponding to the brother who had previously touched the objects. The drawing face corresponding to either Paul or Marc was presented below the pictured objects. Across participants, the surnames of the two brothers—Paul and Marc—as well as the associated faces (sick versus healthy) were counterbalanced across the two picture sets. The participants were instructed to pay attention to each object-face combination presented to them but were not told that they would be tested for their memory of the objects. The object-face stimuli were randomly presented and each pair was displayed on the screen for 6 s. After this encoding phase, as in the previous studies, the participants performed the same two interference tasks for 3 min. Finally, they were given a surprise free recall task that lasted for 5 min. During this, they had to write down all the previously presented words they remembered in any order they liked.

Results and Discussion of Study 4

Objects accompanied by the sick face were recalled significantly better ($M = .54$, $SD = .16$) than objects presented with the healthy face ($M = .48$, $SD = .16$), $t(46) = 2.42$, $p = .019$, $d = 0.39$). The number of extralist intrusions was low ($M = 1$, $SD = 1.25$).

Using the drawing of a face of someone with a respiratory illness such as influenza or a cold, we found that objects touched by someone ill were remembered better than objects touched by someone healthy. We had surmised that the use of different types of contamination cues could have been a key factor driving the memory boost for contaminated things reported by Fernandes et al. (2017). However, the findings of the present study suggest that having different types of contamination cues is not a necessary condition. Thus, the presentation of the same type of disease throughout the encoding phase is sufficient to provide a contamination context for the objects that are associated with it. In the next two studies (studies 5a and 5b), to further establish the robustness of contamination effects in memory, we decided to design two quasi-replications of Fernandes et al.'s experiment 2 (2017), but with important additional inputs. Fernandes et al.'s findings (2017) are very important because they were obtained with real faces depicting real signs of contamination and therefore used an ecological situation. Moreover, different ratings were obtained in the pre-experimental phase of the study showing that contaminated faces elicited more disgust than non-contaminated faces. Since disgust is a key component of the behavioral immune system (Schaller and Park 2011), and because this emotion can boost memory (Chapman et al. 2013; Charash and McKay 2002; Croucher et al. 2011), we wanted to ensure that we would also find a boost in memory when using contaminated faces that elicited some level of disgust and discomfort. Given that Fernandes et al. (2017) did not measure levels of discomfort directly from the participants who were involved in the memory experiment, we decided, in study 5a, to measure this dimension before testing memory of the objects linked to the faces. In Fernandes et al.'s experiment 2 (2017), the participants were explicitly told to memorize the face-object associations but they were not told that they would subsequently have to perform a memory test. Thus, the free recall test involving the object names came as a surprise memory test. In study 5b, as in Fernandes et al., the participants were explicitly instructed to memorize the face-object associations. One important addition in study 5b was that, contrary to Fernandes et al. (2017), we took into account individual differences in disgust sensitivity as well as in fear of contamination. From an evolutionary perspective, it makes sense to remember that an item has been linked with a contaminated thing or someone ill (source memory). In both studies, we therefore followed the object name recall test with a source memory test, i.e., identify whether objects had been touched by a sick or a healthy person.

Study 5. Memorizing Objects Touched by Healthy Versus Contaminated Real Faces

In study 5a, we used an incidental memory procedure. During the presentation of the face-object associations, the participants were told to evaluate their level of discomfort for each pair of stimuli and, after a brief delay, were given a surprise recall test. In study 5b, they were explicitly told to memorize the face-object pairs. A recall test was also used to assess memory of contaminated vs. non-contaminated things. Source memory was also assessed in both studies just after the recall test. Finally, after the memory assessment, the participants completed the perceived vulnerability to disease scale (PVDS, Duncan et al. 2009) and the disgust scale (Haidt et al. 1994), which has been translated into French (Gil et al. 2009). We expected that people who think of themselves as more vulnerable to infectious diseases, and/or who are more easily disgusted, might remember more contaminated items than less disease-vulnerable (disgusted) people. In their experiment 2, Fernandes et al. (2017) did not take account of these individual dispositions. The literature on the behavioral immune system reports evidence that people who feel more vulnerable to disease exhibit elevated ethnocentrism (e.g., Navarrete et al. 2007). Moreover, individuals who are more prone to experiencing disgust are more likely to hold negative attitudes toward certain social groups (e.g., Inbar et al. 2012).

Participants One hundred and sixteen adults (mean age 21.27 years) taken from the same pool as in the previous studies took part in four collective sessions. Forty-six participants (35 females) were involved in study 5a and 70 participants (62 females) in study 5b. More participants were involved in study 5b than in study 5a because we included individual measures on disgust and on perceived vulnerability to disease. They were all native speakers of French and none were taking medication known to affect the central nervous system.

Stimuli

Faces We followed Fernandes et al.'s (2017) procedure described in their experiment 2 to design our face stimuli. First, we selected a set of 48 female faces from the Karolinska Directed Emotional Faces (Lundqvist et al. 1998) and from the Radboud Facial Database (Langner et al. 2010). Then, for each face, we used Gimp software (www.gimp.org) to manipulate the faces in order to display the same conspicuous disease-connoting cues that were chosen by Fernandes et al. (2017), namely perioral dermatitis, conjunctivitis, eczema, herpes, sweet syndrome, ringworm, and butterfly-shaped rash (see Fig. 3 in the Supplemental

Material for illustrations of each conspicuous disease-connoting cue paired with the non-manipulated faces).

Similarly, we used a set of 96 pictures of female faces, half of which depicted healthy faces while the other half depicted the corresponding sick versions. Using Fernandes et al.'s (2017) procedure, we collected norms (using 6-point Likert scales) of perceived disease, disgust, emotional valence, arousal, and discomfort from an independent sample of 46 participants (mean age = 20.92 years) in response to the 96 pictures. Any given participant saw each face in either its sick or its healthy version, but not both (a total of 48 faces rated per participant).

We found that all conspicuous disease-connoting cues were effective at eliciting perceived disease. As a result, we did not exclude any medical condition manipulations from the final selection of sickness representations. Contrary to Fernandes et al. (2017) who found that perioral dermatitis and butterfly-shaped rash were not effective at eliciting disgust, our sick faces were all effective at eliciting disgust, negative and high emotions, as well as discomfort. Within the seven disease categories, we selected the 30 diseased faces that were the most clearly identified as sick (and as healthy for the 'non-manipulated' versions) and that caused the highest levels of disgust and discomfort. *t* tests (Table 3) revealed that the means obtained for the selected faces and for each of the rated dimensions differed reliably between the sick and healthy faces.

Objects As for study 2, the same 30 colorized drawings of objects selected from the Rossion and Pourtois (2004) database were used.

Design In both studies, a within-subject design was used with type of faces (sick vs. healthy) as the independent variable.

Procedure The participants were tested collectively. The instructions were given visually (and simultaneously orally) to the participants. In both studies 5a and 5b, they were told that they would be presented with faces of people. Certain faces would show signs of contamination whereas other faces would depict people in good health. Each face would be accompanied by the colorized drawing of an object. Booklets were provided to the participants at the beginning of each study in order to collect the different responses but in such a way they could not see the forthcoming different response sheets. They could therefore not anticipate the different types of tasks that would be asked to perform.

Table 3 Mean ratings (and standard deviations) for each version of the face stimuli used in the main experiment, obtained from the pilot study (Study 5)

	Healthy faces	Sick faces	*t* test
Perceived disease	1.78 (.41)	4.34 (.31)	$t(58) = -27.08^{**}$
Disgust	1.49 (.34)	3.75 (.39)	$t(58) = -23.51^{**}$
Emotional valence	2.51 (.43)	3.77 (.32)	$t(58) = -12.63^{***}$
Arousal	1.98 (.22)	3.46 (.42)	$t(58) = -16.98^{***}$
Discomfort	1.59 (.39)	3.77 (.40)	$t(58) = -21.03^{***}$

$^{**}p < 0.01$

$^{***}p < 0.001$

In study 5a, the participants were told to indicate on a 5-point scale their perceived level of discomfort if they had to touch and handle the object depicted next to the picture (1 = I would feel very uncomfortable, 5 = it would not bother me at all). They had 6 s in which to answer.

In study 5b, the participants were told to pay attention to each face-object association in order to remember them.

In both studies 5a and 5b, each face-object pair was displayed on the screen for 6 s and the presentation of the face-object pairs was random. There were two versions of the face-object list so that a given face was never presented twice. However, across participants, it was presented in both the contaminated and the non-contaminated version. In both experiments, after the presentation of the stimuli, distractor tasks (the same as those used in the previous experiments) were given to the participants for about 3 min. In both studies 5a and 5b, a 5-min recall test was then performed. The participants had to write down the names of the objects that came to their mind in any order. After the recall test, the participants had to go through the words they had recalled and identify whether the corresponding objects had been touched by a sick or a healthy person, i.e., a source memory task. Finally, and for study 5b only, a number of questionnaires were completed. First, the participants took the perceived vulnerability to disease (PVD) test (Duncan et al. 2009). The PVD scale comprises 15 items designed to assess individual differences in concerns about the transmission of infectious diseases (e.g., *I am more likely than the people around me to catch an infectious disease*). One subscale assesses beliefs about one's own susceptibility to infectious diseases and the second subscale assesses emotional discomfort in contexts that suggest an especially high potential for pathogens. Second, they had to complete the disgust scale (Haidt et al. 1994) which comprises two sets of 16 items: 4 items in each of the 7 animal-reminder domains (food, animals, body products, sex, body envelope violations, death, and hygiene), and 4 items related to magical thinking in relation to these domains. The first set of items requires the participants to circle a yes/no response (e.g., *seeing a cockroach in someone else's house doesn't bother me*) and the second set requires them to choose one of three numerical values for each of 16 items, with 0 corresponding to "not disgusting at all", 1 to "slightly disgusting", and 2 "very disgusting" (e.g., *You see someone put ketchup on vanilla ice cream, and eat it.*, 0, 1 or 2?). The first factorial score resulting from a principal component analysis (PCA) run on the two disgust subscales (81.5% of extracted variance) was taken as a 'global disgust score', with higher values denoting higher disgust scores on both scales (the correlations of factorial scores with both subscales were .9).

Results of Study 5a

Perceived Discomfort The faces with disease-connoting cues (D) were found to produce more discomfort (remember that 1 = *I would feel very uncomfortable*, 5 = *It would not bother me at all*) in a hypothetical situation of touching and interacting with the associated objects than was the case for the healthy faces (H), D: ($M = 2.57$, $SD = .83$) and H: ($M = 3.89$, $SD = .75$), $t(45) = -9.95$, $p < .001$, $d = -1.67$.

Free Recall A significant mnemonic advantage was obtained for objects associated with sick people ($M = .43$, $SD = .12$) compared to those associated with healthy people ($M = .35$, $SD = .12$), $t(45) = 3.59$, $p < .001$, $d = .70$. The number of extralist intrusions ($M = .52$, $SD = .78$) was low.

Overall, there was a significant negative correlation between perceived discomfort and free recall ($r = -.286$, $p = .006$), with the result that the more the participants felt uncomfortable with the idea of touching and interacting with the objects, the better they remembered them.

Source Memory The proportion of times the participants correctly identified the source for the object names they recalled was computed. The source for the objects that had been presented with a sick face was identified better ($M = .76$, $SD = .17$) than the source for the objects presented with a healthy face ($M = .52$, $SD = .25$), $t(45) = 5.81$, $p < .001$, $d = 1.11$. Because the results on source memory could be due to a bias, that is to say attributing a sick source to recalled objects more often than a healthy source, we followed Fernandes et al. (2017) and looked at the source memory for extralist intrusions. The intrusions were low ($n = 24$). We found that 67% were attributed a healthy source and 33% a sick source. Thus, it seems that no bias was present in the source memory data relating to the attribution of sick sources.

Results of Study 5b

Free Recall and Source Memory Objects paired with sick faces were recalled significantly better ($M = .50$, $SD = .16$) than objects paired with healthy faces ($M = .42$, $SD = .15$), $t(69) = 3.025$, $p = .003$, $d = .52$. Also, the sources of objects associated with a sick face were better identified ($M = .76$, $SD = .17$) than the sources of the objects associated with a healthy face ($M = .66$, $SD = .21$), $t(69) = 3.90$, $p < .001$, $d = .54$. Concerning extra-list intrusions ($n = 49$), 55.1% of these were attributed a healthy source and 44.9% a sick source ($p = .504$). Thus, as in study 5a, no bias was observed in the source memory data.

Combined Analysis of Studies 5a And 5b

An ANOVA performed on the recall rates with type of objects (contaminated vs. healthy) as a within-subject factor and type of encoding (implicit [experiment 5a] vs. explicit [experiment 5b]) as a between-subject factor revealed that both main effects were significant, type of objects: $F(1,114) = 18.66$, $p < .001$, $\eta^2_p = .141$; type of encoding: $F(1, 114) = 13$, $p < .001$, $\eta^2_p = .102$, whereas the interaction effect was not, $F(1, 114) = .0031$, $p = .955$. More object names were recalled when a memory test was expected (experiment 5b: $M = .46$, $SD = .11$) than when a surprise test was administrated (experiment 5a: $M = .39$, $SD = .09$). Moreover, recall was better in the contaminated condition than in the healthy condition ($M = .47$, $SD = .15$ and $M = .38$, $SD = .15$). When source memory scores were analyzed in the same way as the recall rates, the two main effects reached significance: type of objects: $F(1,114) = 53.6$, $p < .001$, $\eta^2_p = .32$ and type of encoding: $F(1, 114) = 4.55$, $p = .035$, $\eta^2_p = .038$. The interaction effect was also significant, $F(1, 114) = 8.24$, $p = .005$, $\eta^2_p = .067$. More sources were identified with the explicit memory test (5b: $M = .66$, $SD = .21$) than with the incidental test (5a: $M = .52$, $SD = .25$) in the healthy condition, $F(1, 114) = 9.14$, $p = .003$, $\eta^2_p = .074$, but not in the contaminated condition (5b: $M = .76$, $SD = .17$, 5a: $M = .76$, $SD = .17$, $F(1, 114) = .006$, $p = .939$, $\eta^2_p < .001$. Finally, the source of the items was remembered better in the contaminated condition with both the explicit memory test, $F(1, 114) = 12.48$, $p < .001$, $\eta^2_p = .114$, and the incidental test, $F(1, 114) = 43.04$, $p < .001$, $\eta^2_p = .099$.

Individual Differences The scores obtained for the different questionnaires (PVD, Disgust scale) were introduced one by one as covariates in the analyses of by-participant proportions of free recall and source memory. A mixed linear model including type of objects (contaminated vs. healthy), the covariate, the interaction between these two IVs and by-participant random intercepts was used (no item random effect was included). A dummy variable was used to code type of objects, whereas the interaction between type of objects and the covariate was introduced as the product between the dummy variable and the covariate (the associated coefficient makes it possible to test for a slope difference between type of object or, conversely indicates that the difference in the means between the type of object is modulated by the covariate). The within-subject nature of the design was taken into account by including in the model the participants' random effect. Whatever the dependent variable or the covariate, the interaction was not significant. The same was found for the main effects of the covariates, with the exception of the global disgust score on source memory, $t(68) = 2.55$, $p = .013$, $\beta = .046$[5] with the result that the more sensitive the participants were to disgust, the more likely they were to correctly remember the source of the items. In all the models, the difference between sick and healthy faces was still positive and significant (with disgust scale: $t(136) = 3.05$, $p = .003$, and $t(136) = 3.39$, $p < .001$, for free recall and source memory; with PVD-perceived vulnerability: $t(136) = 3.04$, $p = .003$, and $t(136) = 3.33$, $p < .001$; with PVD-emotional discomfort: $t(136) = 3.04$, $p = .003$, and $t(136) = 3.32$, $p < .001$).

Discussion of Study 5

The main hypothesis that potentially contaminated objects are subject to a memory boost compared to non-contaminated objects was largely confirmed by the findings of studies 5a (incidental encoding) and 5b (explicit encoding). Not only did we find that contaminated items were recalled better than non-contaminated objects, but the sources of objects associated with sick faces were identified better than the sources of objects associated with healthy faces, and the analyses on extra-list intrusions suggested that the findings on source memory were not due to a bias.

It could, at first glance, be argued that tangible signs of infections have to be perceived for contamination effects to occur because we found contamination effects when there were tangible signs of infection on the faces of drawings (study 4) or of real people (study 5). However, it seems that not all signs of contaminations are equally powerful for generating contamination effects in memory since we did not find any contamination effects when we used the drawing of a hand showing signs of contamination due to someone not washing his hand after visiting the toilets (study 3). Importantly, even though visible signs of infection are certainly efficient in triggering disgust and memory mechanisms, contamination effects in memory are also found when verbal statements are used to describe infections (e.g., a running nose) (Fernandes et al. 2017, experiment 1).

As far as individual differences in the perceived vulnerability to disease are concerned, the data therefore provide no support for the hypothesis that individuals who think of themselves as more vulnerable to infectious diseases remember contaminated items or their source better. However, and interestingly, a reliable effect of the disgust scale on source memory was observed, with the result that more easily disgusted participants remembered the source of the items more accurately.

General Discussion

In the literature on human memory, most researchers assume (at least implicitly) that items are equally memorable. By contrast, psychologists who adopt an evolutionary perspective do not think that things are potentially equally memorable or learnable. Instead, they assume that the brain/mind is not a blank slate (Buss 2014; Pinker 2002). Among the core tenets of the adaptive memory view championed by Nairne and colleagues (Nairne 2010; Nairne and Pandeirada 2008; Nairne and Pandeirada 2010) is that information processed in a context of survival and/or reproduction is remembered better than information that is not relevant to these purposes. As reviewed earlier in this article, thus far the adaptive memory view has been substantiated by several types of evidence: the survival processing advantage (e.g., Nairne et al. 2007), animacy effects (Bonin et al. 2014; Nairne et al. 2013; VanArsdall et al. 2013), albeit to a lesser extent, contamination effects (Fernandes et al. 2017; Nairne 2015) and in the context of mating (Pandeirada et al. 2017), and parenting (Seitz et al. 2018).

In a series of five studies, we have provided further evidence of the existence of contamination effects in long-term memory. First of all, as previously shown by Nairne and Pandeirada (2010), we found that items processed for their value in a contamination survival context were remembered better than the same items processed in a (control) non-survival scenario, i.e., a tour guide context. It is important to stress that we modified the scenario used by Nairne and Pandeirada (2010) in a way that rendered the situation more threatening. Importantly, we also found better recall of items when they were processed in a modern contamination scenario (e.g., a scenario in which people become infected during an organized trip in a foreign country). Thus, the contamination memory effect found with the survival encoding scenario was not solely due to the general survival situation. Avoiding contaminating agents and finding ways to fight infections were survival issues in the distant past and the findings from study 1 show that our memory system still has imprints of this type of selection pressure. Second, in studies 4 and 5a and 5b, we found that objects that were reported to have been touched by someone who was a carrier of a dangerous infection were remembered better than objects said to have been touched by someone healthy. However, there was no reliable effect of contamination on recall performance in studies 2 and 3 when objects were imagined as having been touched by an individual who did not wash his hands after visiting the toilet compared to a situation in which the objects were imagined as having been touched by an individual who washed his hands. Why is this? As we explained earlier, it is possible that most of the participants did not feel threatened by the violation of this cultural norm of cleanliness because they knew from experience that touching things held by people who do not wash

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[5] Given that the interaction was not significant, the estimated beta is reported but is not included in the model, thus permitting a similar interpretation for both sick and healthy faces.

their hands after visiting the toilet does not systematically lead to subsequent illness. It is possible that the hands are perceived as providing less reliable information about people's health status than the face because many of the most infectious diseases are associated with facial symptoms (Kouznetsova et al. 2012). Finally, it is also possible that the level of disgust required for memory effects to occur was not reached given that disgusting things are remembered better than both frightening and neutral things (e.g., Chapman et al. 2013). These aspects will need to be tested in further studies.

The primary goal of our research was to provide further evidence for the existence of contamination effects in memory, and we think that the present findings confirm that contamination effects in episodic memory are robust. One critical question is how these effects come about. Our studies were not aimed at testing specific hypotheses about the proximate mechanisms that may underpin these effects. Disgust is a central component of the behavioral immune system (Schaller and Park 2011) and one possibility is that the emotion of disgust mediates contamination effects in memory by triggering certain neural substrates that are known to boost memory, such as the insula (Calder et al. 2000), the connection between the insula and the hippocampus (Augustine 1996), or some interaction of the insula with the amygdala (Chapman 2018). Indeed, although the precise neural substrates linking memory and disgust still have to be identified, there is now good behavioral evidence showing that disgusting things are memorized better than neutral information, and even better than fear-inducing information (Chapman et al. 2013; Charash and McKay 2002; Croucher et al. 2011). In study 5b, we tried to take this issue into account and explored the possibility that individual differences in disgust might modulate contamination effects in memory. Indeed, we found a reliable effect of sensitivity to disgust on source memory performance, with the participants who were more sensible to disgust remembering the (healthy vs. contaminated) sources of the items more accurately. However, and surprisingly, we did not find evidence that participants with high perceived vulnerability to diseases remembered contamination-relevant information, or its source, better. It is possible that the absence of an effect of this factor is due to the use of subjective ratings and that more objective measures would more reliably index vulnerability to disease (e.g., the number of illnesses contracted since childhood). The failure to establish a reliable correlation between perceived vulnerability to disease and memory performance needs further research (see also Prokop et al. 2014 for similar null effects in the domain of self-grooming in humans). Further studies could integrate physiological measures, such as electrodermal responses during the presentation of disgusting and contaminated objects, or behavioral measures of vulnerability to diseases, for instance using a lexical decision task for contamination-relevant and contamination-irrelevant words. Another interesting issue would be to investigate whether hypochondriac participants remember contamination-relevant information better than their non-hypochondriac counterparts.

In the "Introduction", we presented evidence showing that, generally speaking, threatening information is remembered better than non-threatening information. An examination of the literature suggests that there is no straightforward relationship between threat, attention, and memory outputs. For example, concerning the threat of contamination, Ackerman et al. (2009) have shown that, even though face disfigurements (often treated as cues of disease, Faulkner et al. 2004) capture attention, these faces are not particularly well-remembered in the long-term. Alternatively, when self-protective goal states are activated, faces stereotypically perceived as threatening, such as faces of men from out-groups, are particularly well-remembered and this memory boost occurs even if no additional attention is paid to these faces (Becker et al. 2010). In future studies, it would be interesting to track participants' eye movements during the presentation of (sick vs. healthy) face-object pairs in order to investigate how visual attention is focused on the stimuli and identify the relationship between attention and memory in this encoding situation.

With reference to adaptive memory, Fiacconi et al. (2015) examined the idea that the survival processing advantage may be related to threat and provided convincing evidence that the survival processing advantage could be mediated by physiological processes involved in freezing. More specifically, they revealed a parasympathetically dominated heart rate deceleration that reflects the initial stage of defensive engagement. Indeed, they found that words rated in the grassland survival scenario were associated with more extensive heart rate deceleration, and that this physiological outcome was related to recall performance. Given that being contaminated represents a threat to the self, one possibility is that the same kind of psychophysiological processes that have been found to be involved in the survival scenario underpin contamination effects in memory. However, it is also possible that other specific psychophysiological processes are involved in contamination effects. This issue represents an opportunity for future studies.

Being contaminated is obviously a threat and, historically, pathogens have caused many deaths (Murray and Schaller 2016). Therefore, avoiding contamination was one of the most important selection pressures in the distant past (Schaller and Park 2011). However, if people do not seem concerned by certain sources of contamination because they do not know whether and how dangerous for their health they are, or because they are not afraid of being contaminated because they think, for whatever reason, that the situation is not risky *for* *them* (e.g., not washing my hands will not cause me to be sick because I am in good health; not using a condom will not cause me to contract HIV because I am confident that my new sexual partner is cautious), the memory component of the behavioral immune system may not be triggered and, as a result, contaminated things may not be remembered better than non-contaminated things. Fernandes et al. (2017) found that when contaminated faces were presented with objects in a situation that was framed in a non-threatening way (the contaminated faces were of actresses portraying sick people in a TV show), they were not considered to be sources of contamination. As a result, the memory of objects associated with sick faces was not better than that of objects associated with healthy faces. The hypothesis that the cues of potential contamination have to be threatening for contamination effects on memory to occur could account for our failure to find contamination effects on memory in our studies 2 and 3 when participants were presented with objects depicted as being contaminated by someone who did not wash his hands after visiting the toilets. It is possible that the participants did not feel threatened by this contamination situation because they thought that it did not represent a great risk for their health. At the same time, it is also possible that hands are perceived as providing less reliable information about people's health status than the face (Kouznetsova et al. 2012). This hypothesis will have to be tested further. In the literature, it has been shown that signs of pseudo-infections (e.g., birthmarks) can lead to disgust and avoidance behavior (Ryan et al. 2012) and one issue for future work will be to examine the extent to which pseudo-infections can lead to contamination effects in memory in the same way as genuinely contaminating things.

To conclude, taken together, the survival processing advantage, animacy effects, and contamination effects support the adaptive memory view that information related to survival and/or reproduction issues is remembered better than other types of information (Nairne 2010, 2015). Of course, the observation that fitness-related information is remembered better than non-fitness information does not mean that these effects are merely the outcome of an evolutionary module. Indeed, these effects are most probably implemented by different proximate mechanisms which will have to be revealed in future studies. Importantly, this assumption clearly does not rule out an ultimate evolutionary explanation of these effects (Nairne 2013).

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