The psychology of potential threat: Properties of the security motivation system

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ABSTRACT

Results of three experiments support hypothesized properties of the security motivation system, a special motivational system for handling potential threats, as proposed by Szechtman and Woody (2004). First, mild stimuli suggesting potential harm produced a marked state of activation (evident in both objective and subjective measures), consistent with the hypothesis that the security motivation system is finely tuned for the detection of potential threat. Second, in the absence of corrective behavior, this evoked activation is persistent, supporting the hypothesis that once stimulated, the security motivation system produces an enduring motivational state involving the urge to engage in threat-reducing behavior. Third, engagement in corrective behavior was effective in returning activation levels to baseline, whereas cognitive reappraisal was not. These findings are consistent with the hypothesis that deactivation of the security motivation system depends on performance of security-related behaviors, rather than non-behavioral events such as cognitive re-evaluation of threat.

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1. Introduction

One important type of problem that organisms confront in the natural environment is the possibility of events that would have grave consequences if they occurred, yet happen only rarely and can be anticipated only with great uncertainty. Such potential dangers include the possibilities that a predator may be present and that contagion may occur. Potential dangers like these pose some unique challenges. For example, because potential dangers are often hidden (e.g., germs) or not yet present, detecting them must rely on indirect and uncertain cues. Similarly, because of the high cost of error in responding to potential dangers, including death, the possibilities for learning about them through natural consequences are limited; instead, the organism must rely on robust, precautionary responses.

In recognition of these relatively unique challenges, several investigators have proposed that there exists a special motivation system, shaped by evolution for the management of low-probability, high-consequence risks. This biologically ancient neural system has been labeled in various ways, including the "defense system" (Trower et al., 1990), the "hazard-precaution system" (Boyer and Lienard, 2006), the "involuntary risk scenario generating system" (Abed and de Pauw, 1998) and, in our own

work, the "security motivation system" (Szechtman and Woody, 2004; Woody and Szechtman, 2005; Woody et al., 2005). The focus in these theories on uncertainty is related to but distinct from the focus on "threat imminence" in other theoretical approaches (Blanchard and Blanchard, 1988; Craske, 2003; Fanselow, 1994; McNaughton and Corr, 2004). Although distance to the source of danger may often be related to uncertainty, the two can be quite distinct, as in the instance of contact with a substance that may or may not be contaminated. Moreover, the concept of potential danger is more general than threat imminence, which tends to be based on analyses of predator threat. Potential threats take in not only predators, but also threats such as contagion and contamination (disease) and loss of crucial resources (such as food), as discussed in more detail elsewhere (Boyer and Bergstrom, in press; Neuberg et al., in press; Woody and Szechtman, in press).

1.1. The security motivation system

The security motivation system is hypothesized to be a module in the brain that evolved to handle the adaptive problems presented by rare, potentially catastrophic risks such as the potential threats of predation and disease. According to evolutionary psychologists (Pinker, 1997; Tooby and Cosmides, 2006; Trower et al., 1990), such modules are devoted to the detection of relatively specific classes of stimuli, facilitating rapid processing of information of potential relevance for survival and functioning in a relatively automatic and encapsulated way. In addition, they operate as motivational sys-

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tems, whose activation drives relevant responses and temporarily suppresses competing systems (Kavaliers and Choleris, 2001), and they have a characteristic set of species-typical output behaviors.

Research by ethological psychologists and ecologists across a variety of species has examined how animals manage potential threats, such as the danger of predation, and this work reveals the major properties of the security motivation system. First, animals use subtle and indirect cues of uncertain significance to gauge changes in potential danger (Blanchard and Blanchard, 1988; Lima and Bedneckoff, 1999), and assessment of these cues occurs in the absence of any tangible evidence of the presence of a threat, such as a predator (Brown et al., 1999). Wingfield et al. (1998) called these indirect cues "labile perturbation factors," to distinguish them from the presence of imminent danger, and similarly Curio (1993) argued that the diversity of "hidden-risk mechanisms" must be distinguished from predator detection. Thus, the security motivation system performs special types of perceptual processing that may be quite different from those for recognizing imminent danger.

In addition, vigilance and apprehension are readily activated by relatively weak cues suggesting potential danger, and even in the absence of further such cues, this activation dissipates only gradually (Brown et al., 1999; Wingfield et al., 1998; Curio, 1993; Marks and Nesse, 1994; Masterson and Crawford, 1982). Furthermore, activation of the system drives security-related behaviors that are inherently open-ended, in the sense that the animal's environment does not provide any clear consummatory stimulus to signal goal attainment (Szechtman and Woody, 2004). For example, a predator's disappearance from view is not a clear sign of reduced risk (Curio, 1993). Instead, it is the engagement in security-related behavior in itself that appears to generate the internal signal for terminating security motivation (Glickman and Schiff, 1967; Szechtman and Woody, 2004). These behaviors include probing the environment to collect further information about the potential danger and precautionary acts that would help counteract its effects if were to occur. For shutting down security motivation, it is evolutionarily adaptive to rely on performance of such behavior rather than other processes such as cognitive reappraisal, because threat cues may be difficult to evaluate and the costs of inaction are potentially grave (Woody and Szechtman, in press).

Finally, research addressing other behavioral systems that protect animals from noxious events clarifies the ways in which the security motivation system is distinct from them. Ohman and Mineka (2001) have hypothesized that the "fear module" manages escape and avoidance learning through the conditioning of its core motive state of fear to cues of imminent danger, such as the presence of a predator. The security motivation system differs from the fear module in three crucial respects: it operates on subtler, unconditioned stimuli suggesting hidden risk, typically in the absence of manifest danger; its motive state is vigilance and apprehension rather than fear; and its characteristic behavioral output involves probing the environment and precautionary behaviors, rather than avoidance. Likewise, Wingfield et al. (1998) argued that unpredictable environmental changes that may indicate potential danger elicit a pattern of responses that are quite distinct from the fight-or-flight response, both in the kinds of behaviors and their longer time course.

1.2. Indexing activation of the security motivation system: respiratory sinus arrhythmia

Just as the engagement of other motivational systems produces physiological changes that prepare the body for relevant behavior, activation of the security motivation system should yield physiological changes that facilitate engagement in security-related behavior. Because the motor activity engendered by security motivation, such as probing for predators and precautionary washing,

is not physically strenuous, it requires relatively modest energy resources. However, there is the possibility that potential danger could rapidly become real, which would necessitate high energy for engagement in fight-or-flight (Cannon, 1927). In preparation for this possibility, security motivation should mobilize the physiological mechanisms for energy delivery into a state of high preparedness; nonetheless, it should not fully engage them in fuel delivery, because the immediate responses to potential threat, such as precautionary and probing behaviors, do not require strenuous muscular exertion.

This energy preparedness is mediated, at least in part, by the autonomic nervous system. The sympathetic and parasympathetic systems generally work in opposition to each other to regulate internal organs such as the heart and lungs, with the sympathetic system tending to mobilize energy resources and body metabolism for rapid, intense exertion, and the parasympathetic system tending to conserve and replenish energy resources. Security motivation calls for a physiological state lying between these two extremes: a state of high readiness to rapidly support maximal exertion, should this turn out to be needed, while at the same time supporting the relatively modest metabolic demands of ongoing security-related behavior.

Polyvagal theory, as advanced by Porges (2001, 2007b, 2009), explains how the autonomic nervous system produces such a state. The requisite state lies between a state dominated by parasympathetic influence, which facilitates social interactions in environments safe from danger, and a state dominated by sympathetic influence, which facilitates flight-or-flight responses in the face of imminent danger. According to polyvagal theory, there exists an intermediate stage in which attention is directed to the environment because of novelty or potential threat, and parasympathetic influence over the viscera, including the heart and lungs, is attenuated, so that the sympathetic system can be set off quickly if required later.

This potential-threat stage of autonomic function can be indexed objectively by monitoring its effects on heart-rate variability. Specifically, the time series of the intervals between the peaks of the R wave in the electrocardiogram shows oscillations in the frequencies associated with spontaneous breathing (0.12–0.4 Hz), and these oscillations are known as respiratory sinus arrhythmia (RSA). It is the RSA component of heart-rate variability that is sensitive to transitions between safe and potential-threat autonomic stages, and thus can serve as an index of the activation of security motivation.

In particular, RSA is a reflection of neural activity in the nucleus ambiguus-vagal circuit, which exerts an inhibitory effect on the cardiac pacemaker (Porges, 1995). This "vagal brake" (Porges, 2007a) restrains the heart from beating at its intrinsically higher rhythm; in addition, removal of this brake reduces heart-rate variability, because the interval between beats becomes less modulated and hence more regular. Thus, lower variance in the beat-to-beat intervals (as indexed by decreased RSA amplitude in $ln\,ms^2$) indicates a shift from a safe toward a potential-threat autonomic stage. In summary, observed changes in RSA toward less variability should indicate activation of the security motivation system—that is, a state of biological preparedness or readiness, rather than full mobilization. In addition, RSA change has the advantage of being a relatively pure index of vagal brake removal, whereas heart rate is also influenced by other vagal and sympathetic factors.

Further discussion of polyvagal theory and its relation to other theories, such as Gray's motivation theory (Gray, 1982; Gray and McNaughton, 2000), is provided in Beauchaine (2001) and Brenner et al. (2005). More detailed consideration of the neural and physiological bases for the security motivation system is provided in Woody and Szechtman (in press).

1.3. The present experiments

Here, in a series of three experiments, we advance a paradigm to activate security motivation and test the prediction that performance of security-related behavior generates the negative feedback signal necessary to terminate such activation. An additional goal was to establish an experimental paradigm that can be used in future work to test the theory that some types of psychopathology are disorders of security motivation (Flannelly et al., 2007; Szechtman and Woody, 2006), including obsessive–compulsive disorder (Boyer and Lienard, 2006; Szechtman and Woody, 2004). The present experiments examine the following research questions:

A. Does exposure to potential-threat stimuli and engagement in precautionary behavior lead to activation and deactivation, respectively, of the security motivation system?
B. Can RSA be used to provide an objective index of changes in activation of security motivation?
C. Does activation of the security motivation system vary as a function of low to high levels of potential threat, and does such activation persist over time in the absence of precautionary behavior?
D. Finally, is performance of precautionary behavior necessary as a terminator of security motivation, or can cognitive reappraisal of threat substitute for it?

2. Experiment 1

To examine the properties of the SMS, we needed an experimental paradigm to measure how activity of the system changes as a function of exposure to stimuli suggesting potential threat and subsequent engagement in corrective behavior. Experiment 1 compared RSA measured at four successive times: (1) resting baseline; (2) after hand contact with a stimulus; (3) after engagement in a prescribed behavior; and (4) after a final free washing of the hands. There were two experimentally manipulated independent variables. The factor Stimulus involved making hand contact either with soiled-looking diapers or with clean Styrofoam beads. The factor Prescribed Behavior subsequently involved either a 30-s real wash of one's hands in running water, or else a 30-s sham wash, in which participants made the same rubbing movements but with no water.

The research hypothesis was twofold. First, contact with a potentially harmful stimulus would lead to activation of the SMS, as indexed by decreased RSA. Second, engagement in corrective behavior would effectively deactivate the system and thus return RSA to its baseline level.

2.1. Method

2.1.1. Participants

Participants were 76 (57 female and 19 male) university students and other individuals in a university hospital setting. Their mean age was 24.6 years (SD = 7.4), and their mean body weight, height and BMI were 64.4 kg (SD = 10.2), 1.68 m (SD = 0.09), and 22.7 kg/m² (SD = 2.6), respectively. All participants were pre-screened to ensure that they reported no known diagnosis or treatment for problems involving normal heart or lung function, no known allergies, and no known diagnosis or treatment for mood or behavioral disorders. Participants were asked to refrain from coffee and other stimulants for at least 2 h prior to the study, and were asked not to participate if they were currently ill or taking any over-the-counter medication. Participants were randomly assigned to the experimental conditions, subject to the constraint of comparable gender composition across groups. The number of male participants per group was 4 or 5, and the number of females per group was 13–15.

2.1.2. Materials and apparatus

The potentially harmful stimulus involved the implied threat of contamination via germs or disease. Clean diapers were manipulated to appear soiled by using a combination of water, ammonia, yellow food coloring, chocolate and baby oil. Seven of these soiled-looking diapers were piled in a hospital waste bin labeled Pediatrics. As a control condition, we used an unlabeled bin of clean Styrofoam packaging peanuts, which pilot work indicated are a neutral stimulus.

Hand washing took place at a sink fitted with an automatic, motion-activated faucet preset to deliver a consistent flow of warm water (at about 25 °C). For the measurement of RSA, the ECG signal was amplified through the Biopac data acquisition system and sampled at 2000 Hz. A data file of inter-beat intervals was created for each participant, and these data were analyzed using the software MxEdit (Porges and Byrne, 1992), following the described protocol (Porges et al., 2007). Specifically, the program computed the mean heart period, the natural log of the heart period variance, and the RSA index of vagal tone.

2.1.3. Procedure

Each participant remained seated for the duration of the experiment in the immediate vicinity of a sink, easily reached at the required times by simply rotating the chair. The experimenter attached ECG electrodes and familiarized participants with operation of the sink and the hand washing procedure. Participants were instructed that at some point during the experiment, they would be asked to contact a stimulus that might or might not be contaminated.

A 2-min, eyes-closed resting period allowed the collection of the baseline RSA. Next, participants made contact with the stimulus by submerging their left hand and arm into the bin, containing either the soiled-looking diapers or the clean Styrofoam peanuts, and moved their hand through the contents of the bin for 2 min.

Participants were then instructed to remove their hand from the bin, hold it motionless in their lap (to avoid movement artifacts), and focus attention on it with eyes closed. At this time the second 2-min collection of RSA data occurred. Next, participants engaged in a 30-s period of prescribed behavior, in which they either washed their hands in running water or else engaged in the same hand movements, but with no water. A subsequent 2-min resting period with eyes closed allowed the collection of the third sample of RSA data. Finally, all participants washed their hands in water for as long as they wanted and then dried their hands with paper towels. The subsequent 2-min resting period with eyes closed allowed the collection of the fourth sample of RSA data.

After removal of the ECG electrodes, participants retrospectively rated on a scale from one to ten their level of discomfort during contact with the stimulus. These ratings served as a manipulation check and verified that the diapers elicited much higher subjective discomfort than the Styrofoam beads (mean for diapers was 6.7 vs 1.2 for Styrofoam, F(1, 80) = 344.94, p < .001, partial eta squared = .82).

2.2. Results

The principal data in this experiment are the RSA after contact with the stimulus (diapers or Styrofoam beads), the RSA after the prescribed behavior (real or sham washing), and the RSA after the free wash. For each participant, these values were subtracted from baseline RSA, yielding higher scores for higher levels of SMS activation.

The RSA change data were analyzed with multivariate analysis of covariance (MANCOVA), using baseline RSA, age, and sex as covariates. Note that the resulting statistical tests for RSA change using baseline RSA as a covariate are exactly the same as the corresponding tests for the raw RSA level with baseline RSA as a covariate (Dwyer, 1983). The advantage of using RSA change is purely to express a decrease in RSA level as an increase in SMS activation.

Of most relevance, the three-way interaction of Stimulus, Prescribed Behavior, and Time of Measurement was statistically significant, F(2, 68) = 13.78, p < .001, partial eta squared = .29. Fig. 1 shows the relevant adjusted means. As predicted, after contact, the diaper conditions elicited significantly greater RSA change than the Styrofoam conditions, indicating differential activation of the SMS by the potentially harmful stimulus. Also as predicted, at the after-behavior time of measurement, the diapers group who sham-washed continued to show high SMS activation. In contrast, the diapers group who actually washed showed a deactivation to baseline, consistent with the hypothesized deactivation of the SMS. Finally, after the free wash, the diapers group who had previously sham-washed returned to baseline.

3. Experiment 2

To examine how activation of the SMS varies as a function of low to high potential threat, Experiment 2 contrasted five stimulus conditions designed to represent a graded range of levels of poten-
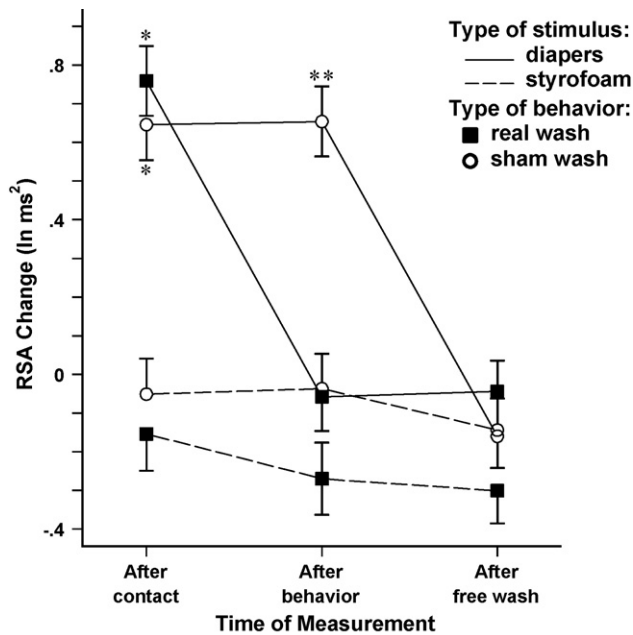
Fig. 1. Effect of behavior on terminating SMS activity. RSA change was computed as baseline RSA minus RSA level; this method permits for a reduction in RSA level to be expressed as an increase in RSA change, corresponding to an increase in SMS activation. *Note:* *$p < .05$ *vs* groups in the Styrofoam stimulus condition at the same time; **$p < .05$ *vs* the other 3 groups at the same time of measurement. Error bars represent 1 SE.

tial threat. It also tracked RSA for a more extended period of time (22 min) in the absence of corrective behavior. The exploration of such across-time dynamics is consistent with Davidson's concept of "affective chronometry," in which the time course of a particular type of emotional response is mapped out to reveal its underlying properties (Davidson, 1998). The graded levels of stimulus were crossed with three times of measurement of RSA: just after contact with the stimulus, 10 min after contact, and 20 min after contact.

In addition to RSA, we also collected subjective ratings of anxiety, contamination, and urge to wash. The research question was how these objective and subjective measures would differ as a function of contact with different stimulus levels, and what time course the measures would show in the absence of corrective behavior.

3.1. Method

3.1.1. Participants

Participants were 75 (38 female and 37 male) university students and other individuals in a university hospital setting, with a mean age of 22.7 years (SD = 5.1). Their mean body weight, height and BMI were 66.6 kg (SD = 12.3), 1.71 m (SD = 0.09), and 22.8 kg/m^2 (SD = 3.1), respectively. Participants were pre-screened as in Experiment 1. Fifteen participants were run in each of the five experimental groups. Participants were asked to refrain from coffee and other stimulants prior to the study. Participants were randomly assigned to the five stimulus conditions, subject to the constraint of comparable gender composition. There were 7–8 male and 7–8 female participants in each group.

3.1.2. Materials and apparatus

The five graded levels of stimulus, listed from lowest to highest in intended intensity, were (1) clean Styrofoam peanuts; (2) clean, dry diapers; (3) wetted (but unstained) diapers; (4) wet, stained diapers (dabbed with yellow food coloring) scented with ammonia; and (5) wet, stained, scented diapers containing simulated feces (smears of chocolate). In all cases, the stimuli were presented in a bin as in Experiment 1.

The measurement of RSA was based on 2-min samples, with the data collected and processed as in Experiment 1.

3.1.3. Procedure

The procedure through 2-min contact with the stimulus and the first 2-min sample of RSA was the same as for Experiment 1. Participants were then asked to indicate their subjective levels of anxiety, contamination, and urge to wash, each by

pointing to the relevant spot on a 15-cm line. For example, in response to the question, "During the last 2 min, how contaminated did you feel?", participants pointed to a line with the end points labeled "not at all contaminated" and "extremely contaminated." Each response was quantified by measuring the distance in centimeters from the lower end point.

For the next 8 min, participants were instructed to sit and wait patiently. Then, 10 min after contact, another 2-min sample of RSA and the three subjective ratings were collected. After a subsequent 8-min waiting period, a final 2-min sample of RSA and set of subjective ratings were collected. At this point, 22 min after exposure to the stimulus, data collection was concluded and participants were allowed to wash their hands.

3.2. Results

RSA values at each of the three time points after contact (immediately after, 10 min after, and 20 min after) were subtracted from baseline RSA. The RSA change data were analyzed with MANCOVA using baseline RSA, age, and sex as covariates. There was a significant main effect of Stimulus Level, $F(1, 67) = 2.71$, $p < .05$, partial eta squared = .14. In contrast, neither the main effect of Time of Measurement nor the interaction of Stimulus Level with Time of Measurement approached statistical significance (both p's > .80). In Fig. 2, the black bars show the adjusted means for RSA for each level of the stimulus, collapsing across time. The main difference is between the Styrofoam beads and all the diaper conditions: All four diaper conditions yielded significantly higher RSA than Styrofoam, but in turn were not significantly different from one another.

The three types of subjective ratings (anxiety, contamination, and urge to wash) were handled as a within-subjects factor and analyzed with a MANCOVA using age and sex as covariates. There were three significant effects: the main effect of Stimulus Level, $F(4, 68) = 6.14$, $p < .001$, partial eta squared = .27; the main effect of Time of Measurement, $F(2, 67) = 7.07$, $p < .01$, partial eta squared = .17; and the interaction of Stimulus Level with Type of Rating, $F(8, 136) = 3.43$, $p = .001$, partial eta squared = .17. The main effect of Time indicated that all subjective ratings tended to decrease modestly across time; collapsing across type of rating, the means were 6.39, 4.32, and 3.86 after contact, 10 min later, and 20 min later, respectively. However, this change did not interact with the other factors. Collapsing across time, Fig. 2 shows the adjusted means of the three types of subjective ratings for each level of the stimulus. A general pattern of increase in subjective ratings with increasing stimulus intensity is evident, with most of the increase appearing over the first three intensities. Collapsing across type of rating,
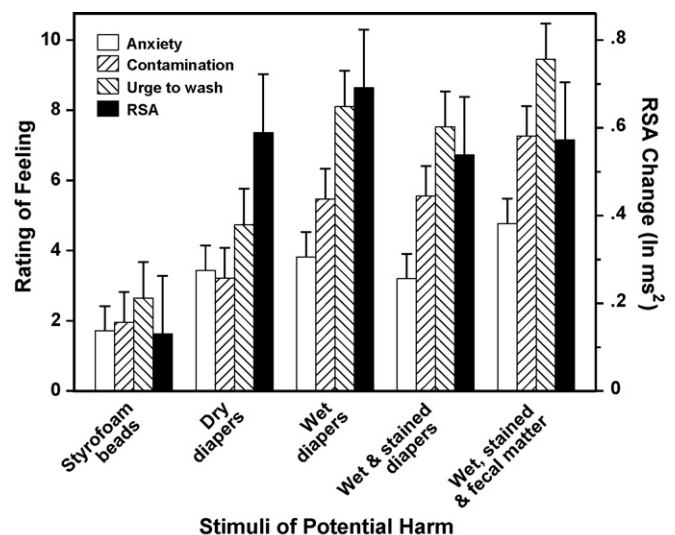

Fig. 2. Response profile of SMS activation to a gradient of potential harm stimuli. Error bars represent 1 SE.

the Styrofoam differs from all the diaper conditions except dry diapers, and dry diapers differ significantly from wet, stained diapers with fecal matter. In addition, consistent with the significant level-by-time interaction, there is a somewhat steeper increase for contamination and urge to wash than for anxiety (for the linear trend component, $p < .001$).

It is the three lowest levels of stimulus intensity (Styrofoam, dry diapers, and wet diapers) that most clearly produced an increase in activation on both objective and subjective measures, with no increase thereafter. This observed relationship in which just a small increase in stimulus intensity (level of contamination) was sufficient to produce the maximal response (here, RSA and subjective ratings) is consistent with previous work on the psychology of contamination, in that nearly maximal response is produced by minimal contact with a putative contagion (Rozin and Fallon, 1987). Whereas the dry diapers showed a significant change in RSA from Styrofoam, the subjective reports only became significantly different from Styrofoam with the greater stimulus intensity of wet diapers. This finding that the RSA change precedes change in subjective report suggests that RSA may be a more sensitive indicator of SMS activation, possibly because subjective report involves the noticing and interpretation of physiological changes.

Another important finding is that the objective measure of activation showed strong persistence over the 22 min after contact with the potentially harmful stimulus, with no significant decrease. Although the subjective measures tended to decrease somewhat over time, this rate of decay was unaffected by stimulus intensity. Overall, these results are consistent with the hypothesis that SMS activation continues for an extended period of time in the absence of corrective behavior.

4. Experiment 3

The results of the previous two experiments demonstrated the following properties of the SMS: (1) contact with the stimulus must suggest potential harm to activate the system; (2) in the absence of corrective action, activation of the system persists strongly (for at least 22 min); and (3) corrective action is very effective in returning the system to baseline. The SMS theory postulates that performance of precautionary behavior is necessary to deactivate security motivation. Thus, an important question for evaluating the theory is whether there are other ways, besides corrective action, to shut down the system. Could post-contact cognitive reappraisal that the stimulus was harmless substitute for the corrective behavior of hand washing? Experiment 3 was designed to investigate this question.

Because Experiment 2 showed that the relatively mild stimulus of wet but unstained diapers was sufficient for strong activation of the SMS, this stimulus was used for the present experiment. One group of participants was provided with information negating the possibility of potential danger before contact with this stimulus, whereas another group was provided with this information only after contact with the stimulus. In addition, a control group was given no information negating the possibility of potential danger.

There were two competing hypotheses. If all that is needed to deactivate the SMS is the cognitive reappraisal that there is no potential harm, then post-contact information should be just as effective as corrective behavior for returning the system to baseline. In contrast, if the activated system requires corrective action to return to baseline, then the post-contact information may have comparatively little effect in reducing the activation of the system. As in Experiment 2, we assessed activation of the SMS using both an objective measure, RSA, and subjective ratings.

4.1. Method

4.1.1. Participants

Participants were 45 (36 female and 9 male) individuals in a university hospital setting. The mean age was 26.5 years (SD = 8.2). Their mean body weight, height and BMI were 66.6 kg (SD = 11.7), 1.71 m (SD = 0.07), and 22.8 kg/m² (SD = 3.1), respectively. Participants were pre-screened as in Experiments 1 and 2. Participants were randomly assigned to groups, subject to the constraint of equal gender composition. There were 15 participants (12 women and 3 men) in each of the three experimental groups. Participants were asked to refrain from coffee and other stimulants.

4.1.2. Materials and apparatus

The stimulus was seven wet (but unstained) diapers in a waste bin labeled Pediatrics. The measurement of RSA was based on 2-min samples, as in the previous experiments.

4.1.3. Procedure

Of the various possible combinations concerning when information could be provided and when hand washing could occur, there were three conditions that were potentially particularly informative and therefore run in this study:

1. *Information before contact*: Participants in this condition were informed before contact with the diapers that the diapers were manipulated to appear wet and soiled, but actually were "clean and unused, and in no way contaminated." Participants were told that the diapers' appearance of being used was created by crumpling clean diapers and wetting them with clean water. After 2 min of contact, RSA was recorded for a 2-min period. Then, in the middle part of the experiment, this group was instructed to wash their hands in water for 30 s. After another 2-min recording period, they were permitted to wash their hands again for as long as they liked, and then there was a final 2-min recording period.
2. *Information after contact*: Participants in this condition were given the same information as the foregoing group, but only post-contact. Specifically, after 2 min of contact with the stimulus followed by a 2-min recording period, the experimenter gave them the information negating potential harm (this information was being given at the time as the foregoing group would be washing their hands). There was then another 2-min recording period, after which, the same as the other groups, they were allowed to wash their hands for as long as they liked. There was then a final 2-min recording period.
3. *No information*: Participants in this condition were never given the information negating potential harm. After 2 min of contact with the stimulus followed by a 2-min recording period, the experimenter instructed them to wash their hands in water for 30 s. There was then another 2-min recording period, after which, the same as the other groups, they were allowed to wash their hands for as long as they liked, followed by a final 2-min recording period.

At the end of each 2-min period for recording RSA, participants were asked to indicate their subjective levels of anxiety, contamination, and urge to wash, using the same scales as in Experiment 2.

4.2. Results

The RSA values at each of the three time points after contact were subtracted from baseline RSA and analyzed with MANCOVA using baseline RSA, age, and sex as covariates. There were two significant effects: the main effect of Group, $F(2, 39) = 9.49$, $p < .001$, partial eta squared = .33; and the interaction of Group with Time of Measurement, $F(4, 78) = 10.98$, $p = .001$, partial eta squared = .36. The left panel of Fig. 3 shows the adjusted means for RSA change. At the first time of measurement, immediately following contact with the diapers, the two groups that had not received information negating potential harm showed significantly greater activation than the group that had received this information before contact. At the second time of measurement, the group that received the post-exposure information negating potential harm remained significantly more activated than the other two groups, who had just completed 30 s of hand washing. Thus, the post-exposure information negating potential harm was not an effective substitute for corrective action. Finally, at the third time of measurement, after the free wash for all groups, the differences between the groups dissipated as they all returned to baseline.

The three types of subjective ratings (anxiety, contamination, and urge to wash) were handled as a within-subjects factor and analyzed with a MANCOVA using age and sex as covariates. There were the same two significant effects as for RSA change: the main effect
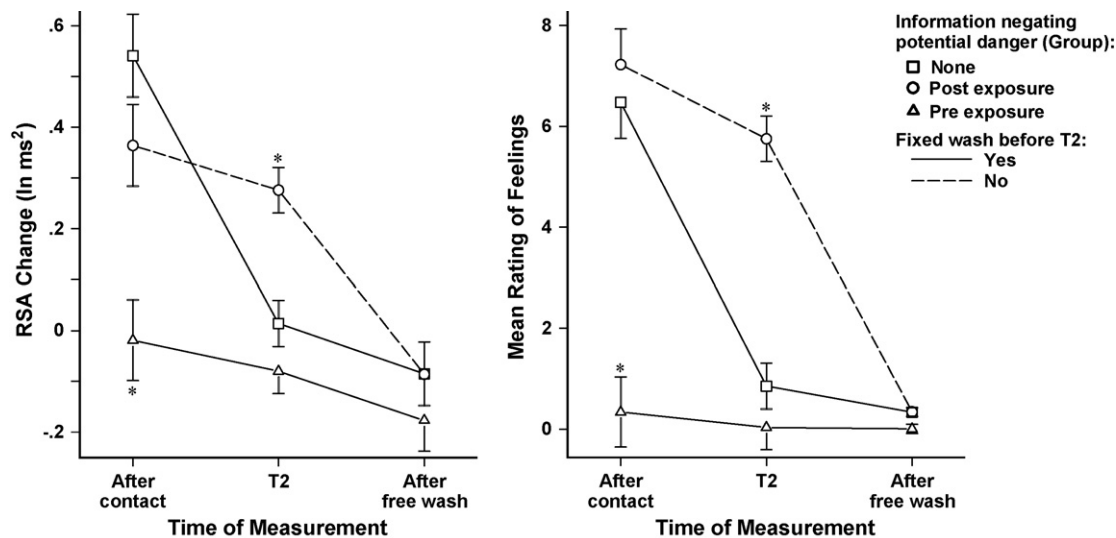
Fig. 3. Effect of cognitive information regarding potential harm on SMS activity. T2 represents the second time of measurement, after either 30 s of fixed wash or the provision of information for cognitive reappraisal of potential harm. Error bars represent 1 SE. *Note*: $^{*}p < .05$ *vs* the other two groups at the indicated time of measurement.

of Group, $F(2, 40) = 33.78$, $p < .001$, partial eta squared = .63; and the interaction of Group with Time of Measurement, $F(4, 80) = 39.52$, $p = .001$, partial eta squared = .66. The right panel of Fig. 3 shows the adjusted means for feelings (collapsing over the three types of ratings, because there were no significant effects involving this factor). The pattern of means and significant differences is the same as for RSA. The comparison of the no information and post-exposure information groups at T2 shows that hand washing was strongly deactivating, whereas the provision of harm-negating information post-exposure was not. Likewise, the comparison of the pre-exposure and post-exposure conditions shows that the same information that prevented activation when provided pre-exposure had no significant deactivating effect when provided post-exposure.

In summary, both objective and subjective measures demonstrated that the deactivation of the SMS required corrective behavior, rather than cognitive reappraisal. Indeed, post-exposure cognitive reappraisal was ineffective even though the same information, when provided before exposure, completely prevented activation of the SMS.

5. General discussion

Taken together, the results of these experiments provide support for important hypothesized properties of the SMS, a special motivational system designed to handle potential threats (Szechtman and Woody, 2004). First, even quite mild stimuli suggesting potential harm produced a marked state of activation (evident in both objective and subjective measures). This finding is consistent with the hypothesis that the SMS is finely tuned for the detection of potential threat. Second, in the absence of corrective action, the evoked activation is very persistent. This finding is consistent with the hypothesis that when stimulated, the SMS produces an enduring motivational state involving the urge to engage in threat-reducing behavior. Third, engagement in corrective behavior was extremely effective in returning activation levels to baseline, whereas post-contact cognitive reappraisal had a negligible effect. These findings are consistent with the hypothesis that deactivation of the SMS depends largely on performance of security-related behaviors, rather than non-behavioral events such as cognitive reinterpretation or re-evaluation of threat.

In addition to lending support for the existence and hypothesized properties of the SMS, the present experiments establish a

paradigm that can be used to investigate further aspects of security motivation. For example, the paradigm will allow us to test the security-motivation hypothesis of obsessive–compulsive behavior (OCD) (Szechtman and Woody, 2004). This theory states that OCD patients lack the normal ability to shut down the SMS by engaging in corrective behavior, which results in an abnormally persistent motivational state and abnormally repeated and extended engagement in corrective behaviors. According to the theory, OCD patients with a contamination/washing profile should differ from control participants mainly in their weaker deactivation upon engaging in corrective behavior. Although the present work used RSA successfully to index SMS activity, future research may supplement this with other physiological indices, particularly because, by itself, a change in RSA does not necessarily reflect the operation of a single particular psychological process (Berntson et al., 2007).

More generally, the theory of a special psychological system for managing potential threats has many implications in current circumstances, in which news of potential threats is transmitted frequently, instantly, and broadly. The theory holds much promise for illuminating the normal psychological processes related to security and precautionary behaviors, as well as contributing to our understanding of some psychological disorders in terms of the psychopathology of security motivation. Future work could also extend the theory by considering the role of individual differences, such as sex and hormonal status (Hahn-Holbrook et al., under review; Taylor et al., 2000) and developmental factors (Boyer and Bergstrom, in press), in the calibration of the system.

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