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Ten years of research with the Socially Evaluated Cold Pressor Test: Data from the past and guidelines for the future

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ABSTRACT

Ten years ago, the Socially Evaluated Cold Pressor Test (SECPT) was introduced as a standardized protocol for the efficient experimental stress induction in humans. In short, the 3 min SECPT, which can be conducted by only a single experimenter, combines a physiological challenge (hand immersion into ice water) with socio-evaluative elements. The purpose of this article is twofold. First, we aim to evaluate the subjective and physiological responses elicited by the SECPT. To this end, we pooled data from 21 studies from our lab and systematically analyzed the response profile to the SECPT. Our analyses show that the SECPT leads, both in men and women, to striking increases in subjective stress levels, autonomic arousal, and cortisol, albeit the cortisol response is typically somewhat less pronounced than in the Trier Social Stress Test. Second, we aim to provide guidelines for conducting the SECPT, in order to foster homogenization of the SECPT procedure across (and within) labs. In sum, we argue that the SECPT is a highly efficient tool to induce stress and activate major stress systems in a laboratory context, in particular if the guidelines that we outline here are followed.

1. Introduction

Stressful encounters, ranging from the many daily hassles to major life-events, are ubiquitous in our everyday life. In healthy humans, these stressors can induce changes in affective and cognitive processing (de Quervain et al., 2017; Joels et al., 2011; Roozendaal et al., 2009; Schwabe et al., 2012; van Stegeren et al., 2005; Vogel et al., 2016), with considerable implications, for instance, for educational contexts (Vanaelst et al., 2012; Vogel and Schwabe, 2016). In vulnerable individuals, stressful events may even contribute to the pathogenesis of mental disorders (Caspi et al., 2003) and, indeed, stress is thought to be a major factor in many psychopathologies, including major depression, schizophrenia, addiction, and posttraumatic stress disorder (de Kloet et al., 2005; Koob, 2008; Walker and Diforio, 1997; Yehuda, 2001). The effects of stress on emotion, cognition, and mental health are mediated by the multitude of hormones, neurotransmitters, and peptides that are released in response to a stressful encounter. Glucocorticoids (mainly cortisol in humans) and catecholamines have been in the spotlight of stress research, although it is well-known that many more substances are involved in the physiological stress response (Joels and Baram, 2009). In the face of the far-reaching consequences of stressful events, it is not surprising that stress is a subject of intense scientific inquiry, with thousands of publications on this topic every year. To investigate the phenomenon stress, its underpinnings and effects, systematically in a laboratory environment, it is essential that standardized protocols are available that reliably induce stress and activate major stress response systems in experimental contexts.

Ten years ago, we introduced in this journal the Socially Evaluated Cold Pressor Test (SECPT) as a highly efficient tool for experimental stress induction in humans (Schwabe et al., 2008). In short, the SECPT is an extension of the classical Cold Pressor Test (CPT; Hines and Brown, 1932), in which participants immerse their hand in ice water, by socio-evaluative elements. Based on meta-analytic evidence that identified social-evaluative elements as crucial for eliciting a robust cortisol response to a stressor (Dickerson and Kemeny, 2004), we reasoned that the addition of socio-evaluative aspects would boost the cortisol response to the cold pressor manipulation, which was often rather moderate in response to the classical CPT (al' Absi et al., 2002; Duncko et al., 2007; McRae et al., 2006). Indeed, we showed in our 2008 report that the cortisol response to the SECPT was significantly stronger than the cortisol response to the CPT (Schwabe et al., 2008), a finding that has subsequently been replicated by others (Smeets et al., 2012; see Fig. 1). Since 2008, the SECPT has been used in numerous studies around the world and it is by now an established standard protocol in human stress research that may represent an efficient alternative to other established protocols, such as the Trier Social Stress

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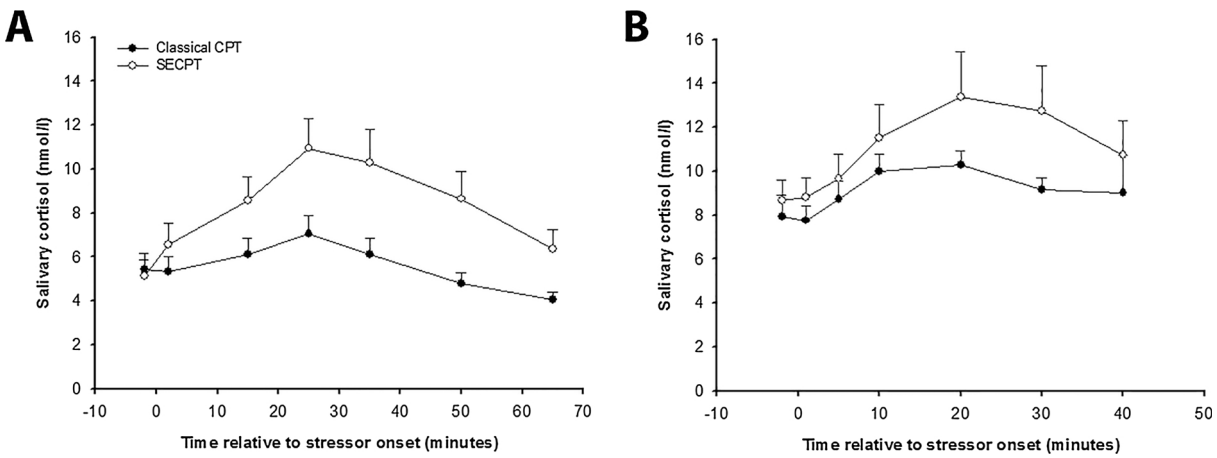

Fig. 1. Comparison of cortisol response to the classical Cold Pressor Test (CPT) and Socially Evaluated Cold Pressor Test (SECPT). The SECPT led both in (A) the study by Schwabe et al. (2008) and (B) the study by Smeets et al. (2012) to a more pronounced cortisol response than the classical CPT. Error bars represent standard error of the mean. The data shown in panel A were provided by courtesy of Dr. Tom Smeets, Maastricht.

Test (TSST; Kirschbaum et al., 1993), a 'gold standard' in the field.

The present article aims to provide a concise overview of the stress response elicited by the SECPT and some guidelines for conducting the SECPT in the lab. In the first part of this article, we will portray the typical subjective and physiological responses to the SECPT. We will focus in particular on the strength of the cortisol response because the SECPT was mainly developed as a tool that leads to a stronger cortisol increase than the classical CPT. In the second part of this review, we will describe in detail how to conduct the SECPT (and its control manipulation). We will clarify issues that have not been made explicit in our 2008 paper or have been further developed based on our experiences with the SECPT. Finally, we will address outstanding issues in the characterization of the stress response to the SECPT.

2. Subjective, autonomic, and cortisol responses to the SECPT

Whether an experimental stress induction was successful (or not) can be assessed at least at three levels: the manipulation should result in the subjective feeling of being stressed, it should lead to marked increases in parameters of sympathetic nervous system activity (such as blood pressure or heart rate), and, last but not least, the manipulation should activate the hypothalamus-pituitary-adrenal (HPA) axis and thus elicit elevated cortisol levels. In order to illustrate the subjective, autonomic, and (salivary) cortisol response to the SECPT, we pooled the data of 21 studies from our labs (see Table 1). In all of these studies, healthy, normal-weighted, medication-free non-smokers between 18 and 40 years of age (n = 1.619; 823 men, 796 women; all women without hormonal contraceptive intake) underwent either the warm water control condition or the SECPT. Both the SECPT protocol and the warm water control condition were conducted as described ten years ago (Schwabe et al., 2008), with only very few variations (e.g. whether there was a different experimenter for the SECPT and whether the gender of this experimenter was opposite to the gender of the participant) as shown in Table 1. Data from these 21 studies were merged and subjected to ANOVAs and *t*-tests in order to assess the average subjective, blood pressure, and salivary cortisol response to the SECPT. Moreover, we used this data set to test whether there are reliable sex differences in the responses to the SECPT and to what extent the outlined variations of the SECPT protocol affected the response to the stressor. As analyses of large data sets such as the present are often overpowered, we present effect sizes in addition to the two-tailed *p*-value to allow an assessment of the actual magnitude of an effect.

Our data confirm that the exposure to the SECPT leads to striking changes in subjective feeling. Fig. 2 shows that participants experience the SECPT typically as being significantly more stressful, painful, and unpleasant than the control manipulation (all $p < 0.001$; all $\eta^2 > 0.50$). In addition to these subjective changes, the SECPT triggers a sharp increase in systolic and diastolic blood pressure (Fig. 3; treatment × time point of measurement interactions: both $p < .001$; both $\eta^2 > 0.30$). This blood pressure increase is maximum during the SECPT and blood pressure returns to baseline quickly as the SECPT is over. Both the subjective and autonomic responses to the SECPT are very robust. We observed highly significant increases in blood pressure and subjective stress levels in each of our studies and we are not aware of any study that did not obtain these SECPT-induced changes. The autonomic changes, however, may not be equally well reflected in all parameters. Blood pressure increases in the SECPT represent at least partly a basic physiological response to cold (vasoconstriction) and this increase in blood pressure may hamper an increase in other autonomic parameters, such as heart rate, due to a baroreflex counterregulation that prevents overshooting of autonomic activity (see also Schwabe et al., 2008). While the increases in subjective stress and autonomic arousal are very robust, they are not at all specific to the SECPT. Significant elevations in subjective stress and autonomic activity are also induced by the classical CPT (Duncko et al., 2007; Hines and Brown, 1932; Schwabe et al., 2008; Smeets et al., 2012) and the CPT and SECPT (as well as the TSST) are comparable in their potency to evoke subjective and autonomic changes (Schwabe et al., 2008; Smeets et al., 2012).

However, previous data suggested that the SECPT results in a stronger cortisol response than the CPT (Fig. 1; Schwabe et al., 2008; Smeets et al., 2012), which is crucial as cortisol is thought to be a driving force in stress effects on emotion and cognition (Buchanan et al., 2006; de Quervain et al., 1998; Joels et al., 2011; Schwabe et al., 2013a,b; Sudheimer et al., 2013; Vogel et al., 2016). So how does the typical cortisol response to the SECPT look like? And how likely is it to occur? Fig. 4 shows that peak cortisol responses can be expected at about 25 min after SECPT onset and that cortisol levels are back at baseline after about 60 min after the beginning of the SECPT. In the pooled studies, the SECPT led on average to a cortisol increase of 4.37 nmol/l, corresponding to a baseline-to-peak increase of about 104 percent. Across studies, the average increase varied between 1.8 and 8.1 nmol/l (corresponding to an increase of 34–127 percent). The strength of the cortisol response was comparable between studies performed in the morning vs. afternoon (time of day × treatment interaction: $p = .76$, $\eta^2 < 0.001$). When participants were classified into cortisol responders and non-responders based on whether they showed a baseline-to-peak cortisol increase of at least 1.5 nmol/l, a cortisol response criterion that was established for the TSST (Miller et al., 2013), the average responder rate across studies was about 60 percent

Table 1
Overview of the pooled studies using the Socially-Evaluated Cold Pressor Test (SECPT).

Study	Sample size	Women/men	Gender of experimenter	Different experimenter for SECPT	Time of day	Design	Additional information	Cortisol increase baseline to peak (nmol/l)	Percentage baseline to peak increase > 1.5 nmol/l
Schwabe and Wolf (2010a)	36	0/36	not systematically controlled	no	am	within	–	5.84	56.1
Schwabe et al., unpublished	70	35/35	male	no	am	between	–	4.00	50.0
Schwabe and Wolf (2011)	76	38/38	not systematically controlled	no	pm	between	–	6.00	57.1
Schwabe et al. (2009)	72	36/36	female	no	pm	between	–	7.14	77.8
Schwabe and Wolf (2009a)	72	36/36	not systematically controlled	no	pm	between	–	2.08	48.4
Schwabe and Wolf (2012)	60	30/30	not systematically controlled	no	pm	between	–	5.24	55.0
Schwabe et al. (2013a,b)	40 (placebo groups only)	20/20	not systematically controlled	no	pm	between	participants received a placebo pill 90 min before the treatment	8.11	84.0
Schwabe et al., unpublished	92	46/46	not systematically controlled	no	pm	between	–	4.29	66.0
Schwabe and Wolf (2010c)	64	32/32	not systematically controlled	no	pm	between	–	3.98	71.0
Schwabe and Wolf (2009b)	80	40/40	not systematically controlled	no	pm	between	–	2.39	48.0
Schwabe and Wolf (2014)	120	60/60	not systematically controlled	no	pm	between	–	4.28	62.0
Schwabe and Wolf (2010b)	68	34/34	not systematically controlled	no	pm	between	–	4.45	50.0
Schwabe et al. (2011)	40 (placebo groups only)	20/20	not systematically controlled	no	pm	between	participants received a placebo pill 45 min before the treatment	6.45	76.0
Kluen and Schwabe, unpublished	65	33/32	opposite to participants gender	yes	pm	between	–	2.27	48.0
Vogel and Schwabe, unpublished	60	30/30	not systematically controlled	no	pm	between	–	3.69	60.0
Bogdanov and Schwabe, unpublished-a	120	60/60	opposite to participants gender	yes	pm	between	–	4.27	57.0
Bogdanov and Schwabe, unpublished-b	68	34/34	opposite to participants gender	yes	pm	between	–	5.41	71.0
Bogdanov and Schwabe, unpublished-c	64	32/32	opposite to participants gender	yes	pm	between	–	4.31	66.0
Kluen et al. (2017), Exp. 1	96	48/48	not systematically controlled	no	pm	between	–	1.81	48.0
Dandolo and Schwabe, unpublished	162	82/80	not systematically controlled	yes	pm	between	–	3.44	50.0
Wirz and Schwabe, unpublished	94	50/44	opposite to participants gender	yes	pm	between	–	4.51	63.4

The last two columns refer to the means in the groups that were exposed to the SECPT.

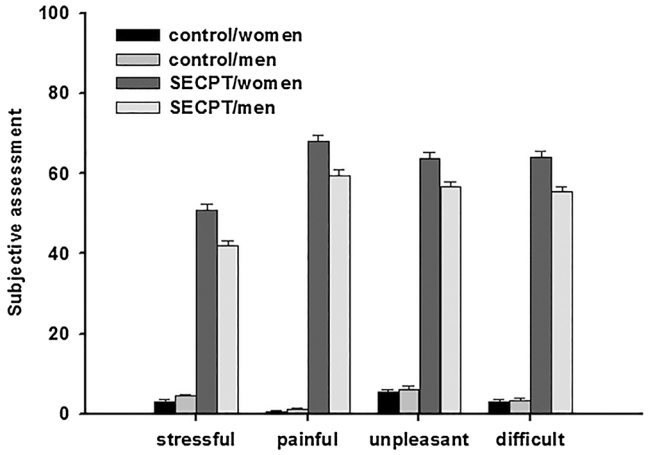

Fig. 2. Subjective assessments of the Socially Evaluated Cold Pressor Test (SECPT) compared to the warm water control condition on a scale from 0 ('not at all') to 100 ('very much'). The exposure to the SECPT was experienced as significantly more stressful, painful, unpleasant and difficult than the exposure to the control manipulation. Shown are pooled data across 18 studies (n = 1.344). Error bars represent standard error of the mean.

(range across studies: 48–84 percent). Thus, the SECPT results in a significant cortisol elevation, although the cortisol response rate may be a bit lower than after exposure to the TSST, which results typically in an average baseline-to-peak increase of about 100 percent, with an average responder rate of 70–75 percent (Kirschbaum et al., 1993; Kudielka et al., 2007; Smeets et al., 2012).

2.1. Differences between men and women

In the face of previous evidence suggesting that stress responses may differ between men and women (Kudielka et al., 2004; Kudielka and Kirschbaum, 2005), we analyzed also potential sex differences in the subjective, autonomic and cortisol responses to the SECPT. Overall, the stress responses to the SECPT were largely comparable in men and women (Figs. 2–4). For subjective and salivary cortisol responses, we obtained in our (overpowered) analysis somewhat stronger subjective responses in women (all $p < .001$; all $\eta^2 > 0.016$) but stronger cortisol responses in men ($p = .013$, $\eta^2 = .005$). The effect sizes, however, were very low and the SECPT-induced increases in subjective stress levels and cortisol concentrations were clearly present in both men and women. For systolic and diastolic blood pressure responses to the SECPT, there were not even statistically reliable differences between men and women (both $p > .28$, $\eta^2 < 0.002$).

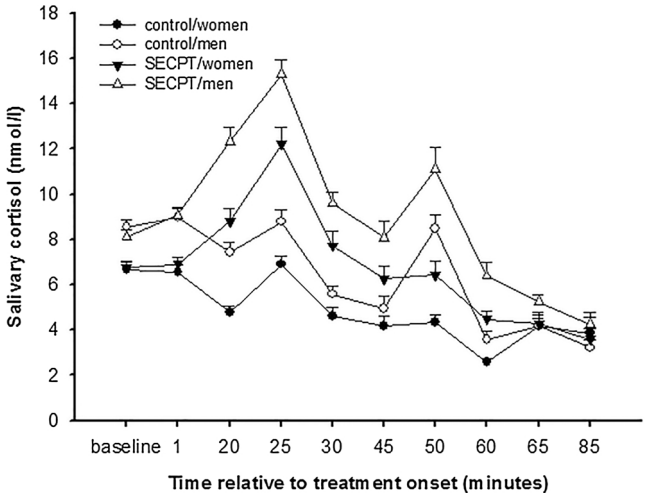

Fig. 4. Salivary cortisol response to the Socially Evaluated Cold Pressor Test (SECPT). Polled data across 21 studies from our labs show that the exposure to the SECPT results in a significant increase in (salivary) cortisol, both in men and women, that reaches its peak at about 25 min after stressor onset (baseline: n = 1.546; +1: n = 1.370; +20: n = 700; +25: n = 649; +30: n = 427; +45: n = 322; +50: n = 206; +60: n = 257; +65: n = 210; +85: n = 211; +100: n = 135). Error bars represent standard error of the mean.

In sum, these pooled data across 21 studies indicate that the SECPT results in marked subjective, autonomic and salivary cortisol changes that are largely comparable in men and women. In terms of the magnitude of the cortisol response, however, there was quite some variation across studies which is most likely due to slight procedural variations between studies (e.g. linked to the specific experimenter). Social-evaluative components and the strict adherence to the SECPT protocol are, based on our experience, essential for the successful stress induction by the SECPT, in particular for eliciting a strong cortisol response. In order to promote homogenization of the SECPT procedure across (and within) labs, we describe the SECPT protocol in detail in the next section.

3. SECPT procedure

An effective stress protocol is assumed to comprise two key ingredients: (i) a task that poses a challenge to the individual, implicating some loss of control and unpredictability, and (ii) social evaluation while performing this task (Dickerson and Kemeny, 2004). Whereas the challenge component (hand immersion in ice water) is rather easily feasible in the SECPT, and unpredictability evolves as a consequence of

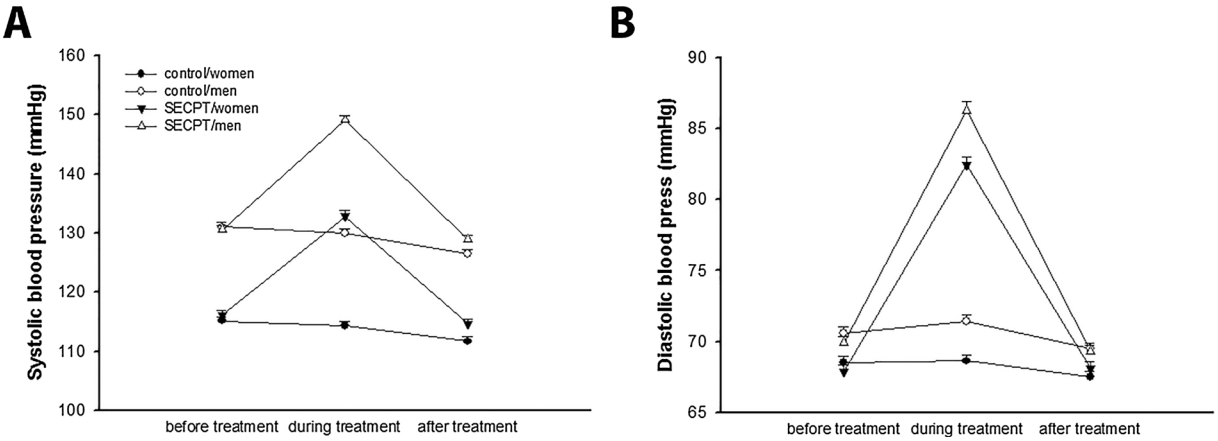

Fig. 3. Blood pressure response to the Socially Evaluated Cold Pressor Test (SECPT). The exposure to the SECPT results in both men and women to a robust increase in (A) systolic and (B) diastolic blood pressure, although blood pressure is generally higher in men than in women. Shown are pooled data across 20 studies (n = 1.546). Error bars represent standard error of the mean.

Table 2
Examples of instructions for the SECPT and control manipulation.

Socially Evaluated Cold Pressor Test (SECPT)	*In the following part of the experiment, you are asked to immerse your dominant hand, including the wrist, into a tank containing ice water. Please keep your hand in the water. The experimenter will let you know when you are allowed to take your hand out of the water. Only if you are not able to tolerate the cold water any more, you are allowed to take your hand out of the water before you are told to do so by the experimenter. However, please keep your hand in the water for* ***as long as possible****!* *During the hand immersion, your facial expression will be videotaped. Please look into the camera all the time and please do not speak.*
Warm water control manipulation	*In the following part of the experiment, you are asked to immerse your dominant hand, including the wrist, for 3 minutes into a tank containing warm water. The experimenter will let you know when the 3 minutes are over and you are allowed to take your hand out of the water.* *This procedure serves as a control manipulation and is experienced as rather neutral by most participants.*

Table 3
Key ingredients for successful stress induction by the SECPT.

Uncertainty	Do not tell the participant how long the hand immersion will last.
Consistency	Avoid switching between roles. This is particularly relevant if there is only one experimenter for all parts of the experiment. In this case, be rather neutral from the beginning on.
Cold stress	Make sure the water is indeed cold enough (0–2 °C) and that the participant keeps his/her hand in the water all the time, without moving or making a fist
Continuous evaluation	Take notes and make the participant feel being evaluated all the time during the hand immersion.
Self-monitoring	Turn the camera screen towards the participant so that he/she can see his/her face on the screen. If possible, use a bigger screen in addition.
Lack of social support or reinforcement	Be reserved, keep the interaction to a minimum, and avoid any form of reinforcement (e.g. smiling).

the unknown task duration, the effective social evaluation is more difficult. It is, however, in particular this social evaluative component that is critical for the success of the SECPT (Schwabe et al., 2008). So how to perform the SECPT to trigger a pronounced stress response? Below, we provide an overview of the SECPT procedure as conducted in our labs, with guidelines that are based on our extensive experience with this protocol.

Before the beginning of the SECPT, we recommend, if possible, a resting period of 30–45 min to allow participants to acclimatize to the lab environment, which appears to be of particular value for a reliable assessment of the autonomic response to the stressor against the background of the 'true' baseline (Linden and McEachern, 1985). If there is only one experimenter for all parts of the experiment, including the SECPT, it is important to keep the interaction to the necessary from the beginning on (without being impolite). Otherwise, it may be difficult (and less convincing) to shift from a friendly chat to the role of the reserved experimenter later on. The SECPT starts with written instructions (for an example see Table 2). These instructions should not contain any information about the duration of the treatment. Further, all watches and time indications should be removed. Should a participant ask for the duration of the hand immersion, we recommend to reply that he/she will be informed when he/she is allowed to take the hand out of the water. While the participant reads the instruction, the experimenter directs the video camera to the participant and zooms in on the participants face. Participants have to sign a separate form in which they declare their consent that video recordings can be taken and that these recordings may be used for scientific purposes (including presentations in lectures and talks) later on. Participants are instructed to look into the video camera all the time. In addition, the screen of the video camera is turned in the direction of the participant so that he/she can see himself/herself on the screen. More recently, we presented also a big TV screen behind the video camera on which participants could see themselves to increase self-monitoring effects (Denson et al., 2012). Afterwards, a tank filled with ice water (0–2 °C) is placed next to the participant. The experimenter should stand in front of the participant, with some distance to the camera, so that participant, camera and experimenter form an equilateral triangle and the participant can see the experimenter from the corner of his/her eye while looking into the camera. If everything is set-up, the experimenter asks the participant to immerse his/her hand into the ice water. The hand should be submerged including the wrist and the experimenter should make sure that the hand is not moved and that participants do not make a fist. During hand immersion, the experimenter should further continuously evaluate the participant, i.e., the experimenter should monitor the participant and take notes. In addition, the experimenter should avoid any form of positive reinforcement (e.g. smiling, nodding). The participant is not allowed to talk during the SECPT and should he/she stop looking into the camera, the experimenter asks the participant to look into the camera again. After three minutes, the participant is allowed to take the hand out of the water, the camera is turned off and the experimenter interacts in a less reserved manner. If a participant takes the hand out of the water before the three minutes are over, he/she is first told that most participants keep their hand in the ice water for a longer time and he/she is asked to submerge it into the water again. If the participant cannot tolerate the ice water any longer and takes his/her hand out of the water, it is important that he/she remains in the socio-evaluative situation, i.e., the video recordings and the evaluation by the experimenter continue until the three minutes are over. The key elements of the SECPT are summarized in Table 3.

3.1. Control manipulation

Participants who undergo the control manipulation receive also written instructions (Table 2). These instructions, however, inform the participants about the duration of the manipulation and participants are also explicitly told that this is a control manipulation. Although this explicit instruction may provoke, for example, framing effects, not telling the participants that this is a control manipulation might make them suspicious and induce a variable degree of uncertainty. In the control manipulation, participants immerse their hands in warm water (35–37 °C), they are not videotaped and not evaluated by the experimenter.

4. Frequently asked questions

4.1. Does the sex of the experimenter matter?

In our original study from 2008 (Schwabe et al., 2008), male participants were evaluated by a female experimenter. Since then, we have been asked repeatedly whether the experimenter in the SECPT should have the opposite sex relative to the participant. In some of our studies we did explicitly evaluate the participant by an experimenter of the opposite sex, whereas we did not in other studies. To explicitly assess the role of the experimenter's sex in the response to the SECPT, we now

compared the subjective and physiological stress responses to the SECPT in studies in which the SECPT was conducted by an experimenter of the opposite sex to those in which the sex of the experimenter was not systematically varied depending on the sex of the participants. Overall, the influence of the sex of the experimenter was rather small. The subjective, (systolic) blood pressure, and cortisol responses to the SECPT were largely comparable in studies that took the sex of the experimenter into account and those that did not (all $F < 1.7$, all $p > .19$, all $\eta^2 < 0.01$). Only for diastolic blood pressure, we obtained significantly higher values in studies in which the experimenter had the opposite sex to the participant vs. those in which the experimenter's sex was not systemically controlled for ($F(1, 729) = 6.98$, $p = .008$, $\eta^2 = 0.009$). However, even for diastolic blood pressure the effect of the experimenter's sex was very small. Thus, although an opposite-sex experimenter might have (small) potentiating effects, for the successful stress induction by the SECPT it appears not to be essential to have an experimenter of the opposite sex.

4.2. Is one experimenter indeed sufficient?

In our original protocol (Schwabe et al., 2008), there was only one experimenter and in many of the following SECPT studies we had only one experimenter that conducted the SECPT as well as the rest of the experiment (e.g. cognitive testing before or after the SECPT). In six more recent studies, however, we used two experimenters, one who did exclusively the SECPT and one who guided the participant through the rest of the experiment (see Table 1). To assess the impact of a different experimenter for the SECPT for the stress response profile, we compared the stress responses in the six studies using two experimenters to six studies with a comparable sample size, in which there was only one experimenter for all parts of the experiment. This analysis showed that the additional experimenter did not lead to increases in the subjective stressfulness, unpleasantness, difficulty or painfulness of the SECPT (all main effects and interaction effects including the factor number of experimenters: all $F < 1.3$, all $p > 0.25$, all $\eta^2 < 0.003$). Systolic and diastolic blood pressure were overall higher when a different experimenter conducted the SECPT (main effects of number of experimenter: both $F > 40$, both $p < .001$, both $\eta^2 > 0.04$). However, the specific increase in systolic and diastolic blood pressure in response to the SECPT remained unaffected by the different experimenter for the SECPT (time point of measurement × treatment × number of experimenters and treatment × number of experimenters interactions: all $F < 2.1$, all $p > .13$, all $\eta^2 < 0.003$). Likewise, the cortisol response to the SECPT was comparable in studies that used a single experimenter for all parts of the experiments and studies in which a different experimenter conducted the SECPT (main effect experimenter and experimenter × treatment interaction: both $F < 0.60$, both $p > .46$, both $\eta^2 \leq 0.001$). Thus, having two experimenters does not seem to boost the subjective and physiological responses to the SECPT and the fact that the SECPT (as well as other parts of the experiment) can be performed by just a single experimenter is one of the advantages of this stress protocol which makes it more efficient than other stress protocols that are available (such as the TSST).

4.3. What should I do if a participant takes the hand out of the water before the 3 min are over?

Based on our experience, most participants keep their hand in the water until they are allowed to take their hand out of the water. In the pooled 21 studies, only about 15 percent of the participants that underwent the SECPT took their hand out of the water before the 3 min were over, without significant differences between men and women ($\chi^2 = 2.43$, $p = 0.12$). For those who cannot tolerate the ice water anymore, it is crucial that they remain in the stress situation, i.e. the evaluation by the non-reinforcing experimenter continues, participants are further videotaped and required to look into the camera (see Section 3). The salivary cortisol and blood pressure response to the SECPT are typically comparable in those participants who keep their hand in the water for the full 3 min and those who take their hand out earlier (but remain in the stress situation; both $F < 0.05$, both $p > 0.60$, both $\eta^2 < 0.01$). At the subjective level, participants who took their hand out of the water before the 3 min were over report typically that they rated the situation even more stressful, painful, unpleasant, and difficult than those who kept their hand in the water for the full 3 min (all $F > 15$, all $p < 0.001$, all $\eta^2 > 0.02$), although it remains unclear whether they indeed experienced the situation as more stressful or whether their ratings were also affected by a 'need for justification'.

5. Conclusion and outstanding issues

The SECPT is an effective and highly efficient protocol to experimentally induce stress in humans. It leads reliably to marked subjective and physiological stress responses. In particular, the strict social evaluation during the hand immersion into ice water results in stronger cortisol responses than typically observed in the classical CPT (Schwabe et al., 2008; Smeets et al., 2012). Compared to other established stress protocols, such as the TSST (Kirschbaum et al., 1993; or the Maastricht Acute Stress Test (MAST, Smeets et al., 2012)), its short duration and the fact that it can be conducted by just a single experimenter make the SECPT a highly efficient tool for stress induction. The short duration of the SECPT may turn out to be particularly advantageous in studies that aim to examine the influence of stress-induced cortisol in a subsequent test that requires some preparation (e.g. when EEG or fMRI measurements will be taken). Peak cortisol concentrations are expected at 25–30 min after stressor onset, irrespective of the nature or duration of the stressor (e.g. Kirschbaum et al., 1993; Schwabe et al., 2008). Thus, after the 3 min SECPT about 20–25 min are left for preparations for subsequent (MRI or EEG) testing, whereas the interval between the end of the TSST and the cortisol peak is only about 10 min, which might be relatively short for EEG or fMRI preparations. The efficiency of the SECPT, however, may come at the cost of a reduced cortisol responder rate: while the cortisol responder rate for the SECPT is typically between 60 and 65 percent, it is typically about 75 percent in the TSST (Kirschbaum et al., 1993; Schwabe et al., 2008; Smeets et al., 2012). The more moderate cortisol responder rate in the SECPT may be beneficial for analyses of the role of stress-induced cortisol in, for instance, stress effects on emotion and cognition (e.g. it allows as separation of cortisol responders and non-responders, in addition to correlational or regression analyses including stress-induced cortisol). However, the typical responder rate should be taken into account already when designing the experiment (e.g. it might be reasonable to include more participants in the SECPT group than in the control group). Finally, it is important to note that the SECPT, the responses elicited by the SECPT and the factors affecting the efficacy of the SECPT are clearly less well studied than the long-established TSST (e.g. DeRijk et al., 2006; Kirschbaum et al., 1999; Kirschbaum et al., 1995; Kudielka et al., 2004; Kudielka et al., 2007; Kudielka and Kirschbaum, 2005). Given that both the TSST and the SECPT rely heavily on social-evaluative components, it is likely that modulators of the stress response that were identified in the TSST will be relevant for the SECPT as well. Nevertheless, it would certainly be important to better characterize, for instance, the neuroendocrine response profile (beyond salivary cortisol) to the SECPT or to test to what extent there are habituation effects to the SECPT. Moreover, while we assessed here the impact of several variations in the SECPT protocol on the stress response across studies, studies addressing specific features of the SECPT protocol explicitly would be highly desirable. For instance, although our analysis across studies did not yield evidence for a role of experimenter's sex on the responses to the SECPT, studies using a fully-crossed design with the factors sex of the experimenter and sex of the participant could directly address this issue. Finally, it should be tested to what extent the individual response to the SECPT and other stress protocols, such as the TSST, are correlated. If

these responses are highly correlated and the cross-protocol habituation is rather low, then the use of different protocols may be very helpful in pre-post designs.

In the end, the choice which stress protocol to use in a given study will depend critically on the specific objectives of the study and the specific experimental design. Research over the past decade has shown that the SECPT results in marked subjective and physiological stress responses, in particular when the procedure that we outlined above is followed. We hope that the SECPT will continue to make a valuable contribution to the experimental investigation of stress and its impact on various aspects of emotion, cognition and well-being in the decades to come.

Contributors

L. S. drafted the manuscript, H. S. provided revisions. Both authors contributed to and have approved the final manuscript.

Disclosure

None of the authors has any biomedical conflicts of interest.

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References

al' Absi, M., Petersen, K.L., Wittmers, L.E., 2002. Adrenocortical and hemodynamic predictors of pain perception in men and women. Pain 96, 197–204.
Buchanan, T.W., Tranel, D., Adolphs, R., 2006. Impaired memory retrieval correlates with individual differences in cortisol response but not autonomic response. Learn. Mem. 13, 382–387.
Caspi, A., Sugden, K., Moffitt, T.E., Taylor, A., Craig, I.W., Harrington, H., Poulton, R., 2003. Influence of life stress on depression: moderation by a polymorphism in the 5-HTT gene. Science 301, 386–389.
de Kloet, E.R., Joels, M., Holsboer, F., 2005. Stress and the brain: from adaptation to disease. Nat. Rev. Neurosci. 6, 463–475.
de Quervain, D., Roozendaal, B., McGaugh, J.L., 1998. Stress and glucocorticoids impair retrieval of long-term spatial memory. Nature 394 (6695), 787–790.
de Quervain, D., Schwabe, L., Roozendaal, B., 2017. Stress: glucocorticoids and memory: implications for treating fear-related disorders. Nat. Rev. Neurosci. 18, 7–19.
DeRijk, R.H., Wüst, S., Meijer, O.C., Zennaro, M.C., Federenko, I., Hellhammer, D., De Kloet, E.R., 2006. A common polymorphism in the mineralocorticoid receptor modulates stress responsiveness. J. Clin. Endocrinol. Metab. 91 (12), 5083–5089.
Denson, T.F., Creswell, J.D., Granville-Smith, I., 2012. Self-focus and social evaluative threat increase salivary cortisol responses to acute stress in men. J. Behav. Med. 35, 624–633.
Dickerson, S.S., Kemeny, M.E., 2004. Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. Psychol. Bull. 130, 355–391.
Duncko, R., Cornwell, B., Cui, L., Merikangas, K.R., Grillon, C., 2007. Acute exposure to stress improves performance in trace eyeblink conditioning and spatial learning tasks in healthy men. Learn. Mem. 14, 329–335.
Hines, E.A., Brown, G.E., 1932. A standard stimulus for measuring vasomotor reactions: its application in the study of hypertension. Proc. Staff Meet Mayo Clinic 7, 332.
Joels, M., Baram, T.Z., 2009. The neuro-symphony of stress. Nat. Rev. Neurosci. 10, 459–466.
Joels, M., Fernandez, G., Roozendaal, B., 2011. Stress and emotional memory: a matter of timing. Trends Cogn. Sci. 15 (6), 280–286.
Kirschbaum, C., Pirke, K.M., Hellhammer, D.H., 1993. The ‘Trier Social Stress Test' – a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 28, 76–81.
Kirschbaum, C., Pruessner, J.C., Stone, A.A., Federenko, I., Gaab, J., Lintz, D., Hellhammer, D.H., 1995. Persistent high cortisol responses to repeated psychological stress in a subpopulation of healthy men. Psychosom. Med. 57, 468–474.
Kirschbaum, C., Kudielka, B.M., Gaab, J., Schommer, N.C., Hellhammer, D.H., 1999. Impact of gender, menstrual cycle phase: and oral contraceptives on the activity of the hypothalamus-pituary-adrenal axis. Psychosom. Med. 61, 154–162.
Kluen, L.M., Nixon, P., Agorastos, A., Wiedemann, K., Schwabe, L., 2017. Impact of stress and glucocorticoids on schema-based learning. Neuropsychopharmacology 42, 1254–1261.
Koob, G.F., 2008. A role for brain stress systems in addiction. Neuron 59, 11–34.
Kudielka, B.M., Kirschbaum, C., 2005. Sex differences in HPA axis responses to stress: a review. Biol. Psychol. 69 (1), 113–132.
Kudielka, B.M., Buske-Kirschbaum, A., Hellhammer, D.H., Kirschbaum, C., 2004. HPA axis responses to laboratory psychosocial stress in healthy elderly adults, younger adults, and children: impact of age and gender. Psychoneuroendocrinolgy 29, 83–98.
Kudielka, B.M., Hellhammer, D.H., Kirschbaum, C., 2007. Ten years of research with the trier social stress test (TSST) – revisited. In: Harmon-Jones, E., Winkielman, P. (Eds.), Social Neuroscience. Guilford Press, New York, pp. 56–83.
Linden, W., McEachern, H.M., 1985. A review of physiological prestress adaptation: effects of duration and context. Int. J. Psychophysiol. 2, 239–245.
McRae, A.L., Saladin, M.E., Brady, K.T., Upadhyaya, H., Back, S.E., Timmermann, M.A., 2006. Stress reactivity: biological and subjective responses to the cold pressor and trier social stressors. Hum. Psychopharmacol. 21, 377–385.
Miller, R., Plessow, F., Kirschbaum, C., Stalder, T., 2013. Classification criteria for distinguishing cortisol responders from nonresponders to psychosocial stress: evaluation of salivary cortisol pulse detection in panel designs. Psychosom. Med. 75, 832–840.
Roozendaal, B., McEwen, B.S., Chattarji, S., 2009. Stress: memory and the amygdala. Nat. Rev. Neurosci. 10, 423–433.
Schwabe, L., Wolf, O.T., 2009a. The context counts: congruent learning and testing environments prevent memory retrieval impairment following stress. Cogn. Affect Behav. Neurosci. 9 (3), 229–236.
Schwabe, L., Wolf, O.T., 2009b. Stress prompts habit behavior in humans. J. Neurosci. 29 (22), 7191–7198.
Schwabe, L., Wolf, O.T., 2010a. Emotional modulation of the attentional blink: is there an effect of stress? Emotion 10 (2), 283–288.
Schwabe, L., Wolf, O.T., 2010b. Socially evaluated cold pressor stress after instrumental learning favors habits over goal-directed action. Psychoneuroendocrinology 35, 977–986.
Schwabe, L., Wolf, O.T., 2010c. Stress impairs the reconsolidation of autobiographical memories. Neurobiol. Learn Mem. 94 (2), 153–157.
Schwabe, L., Wolf, O.T., 2011. Stress increases behavioral resistance to extinction. Psychoneuroendocrinology 36 (9), 1287–1293.
Schwabe, L., Wolf, O.T., 2012. Stress modulates the engagement of multiple memory systems in classification learning. J. Neurosci. 32 (32), 11042–11049.
Schwabe, L., Wolf, O.T., 2014. Timing matters: temporal dynamics of stress effects on memory retrieval. Cogn. Affect Behav. Neurosci. 14 (3), 1041–1048.
Schwabe, L., Haddad, L., Schachinger, H., 2008. HPA axis activation by a socially evaluated cold pressor test. Psychoneuroendocrinology 33, 890–895.
Schwabe, L., Bohringer, A., Wolf, O.T., 2009. Stress disrupts context-dependent memory. Learn. Mem. 16, 110–113.
Schwabe, L., Höffken, O., Tegenthoff, M., Wolf, O.T., 2011. Preventing the stress-induced shift from goal-directed to habit action with a beta-adrenergic antagonist. J. Neurosci. 31 (47), 17317–17325.
Schwabe, L., Joëls, M., Roozendaal, B., Wolf, O.T., Oitzl, M.S., 2012. Stress effects on memory: an update and integration. Neurosci. Biobehav. Rev. 36 (7), 1740–1749.
Schwabe, L., Höffken, O., Tegenthoff, M., Wolf, O.T., 2013a. Stress-induced enhancement of response inhibition depends on mineralocorticoid receptor activation. Psychoneuroendocrinology 38, 331–338.
Schwabe, L., Tegenthoff, M., Höffken, O., Wolf, O.T., 2013b. Mineralocorticoid receptor blockade prevents stress-induced modulation of multiple memory systems in the human brain. Biol. Psychiatry 74, 801–808.
Smeets, T., Cornelisse, S., Quaedflieg, C.W.E.M., Meyer, T., Jelicic, M., Merckelbach, H., 2012. Introducing the Maastricht Acute Stress Test (MAST): a quick and non-invasive approach to elcicit robust autonomic and glucocorticoid stress responses. Psychoneuroendocrinolgy 37, 1998–2008.
Sudheimer, K.D., Abelson, J.L., Taylor, S.F., Martis, B., Welsh, R.C., Warner, C., Liberzon, I., 2013. Exogenous glucocorticoids decrease subgenual cingulate activity evoked by sadness. Neuropsychopharmacology 38, 826–845.
van Stegeren, A.H., Goekoop, R., Everaerd, W., Scheltens, P., Barkhof, F., Kuijer, J.P.A., Rombouts, S.A.R.B., 2005. Noradrenaline mediates amygdala activation in men and women during encoding of emotional material. Neuroimage 24, 898–909.
Vanaelst, B., Huybrechts, I., De Bourdeaudhuij, I., Bammann, K., Hadjigeorgiou, C., Eiben, G., Consortium, I., 2012. Prevalence of negative life events and chronic adversities in European pre- and primary-school children: results from the idefics study. Arch. Public Health 70, 26.
Vogel, S., Schwabe, L., 2016. Learning and memory under stress: implications for the classroom. Sci. Learn. 1, 16011.
Vogel, S., Fernandez, G., Joëls, M., Schwabe, L., 2016. Cognitive adaptation under stress: a case for the mineralocorticoid receptor. Trends Cogn. Sci. 20 (3), 192–203.
Walker, E.F., Diforio, D., 1997. Schizophrenia: a neural diathesis-stress model. Psychol. Rev. 104, 667–685.
Yehuda, R., 2001. Biology of posttraumatic stress disorder. J. Clin. Psychiatry 62, 41–46.