Received: 5 October 2016 | Revised: 30 April 2017 | Accepted: 8 June 2017

DOI: 10.1111/psyp.12956

ORIGINAL ARTICLE

WILEY PSYCHOPHYSIOLOGY SPR

The Pinocchio effect and the Cold Stress Test: Lies and thermography

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Funding information
CONICYT Chile (FONDECYT 1160368)

Abstract

We applied the use of thermography to cognitive neuropsychology, particularly as an objective marker of subjective experiences, in the context of lying. We conducted three experiments: (a) An important lie was invented by the participants in 3 min, and it was recounted by phone to a significant person while they were recorded by the thermographic camera, obtaining a face and hands map of the lie. (b) A similar methodology was carried out, but adding the Cold Stress Test (CST) of the dominant hand during the phone call, obtaining a second physiologic marker (the percentage of thermal recovery) to detect the lie. Further, it established a control condition where it generated anxiety in the participants using IAPS images with negative valence and high arousal, which were described by phone to a loved one. We obtained results that showed significant correlations between changes in body temperature and mental set. Of particular interest was the temperature of the nose and hand, which tended to decrease during lying (Experiment 1). The participants also showed a lower recovery of the temperature after the CST when they were lying (Experiment 2). (c) Experiment 3 is a replication of Experiment 2 but with a different type of lie (a more ecological task) in a different scenario (following the ACID interview, with the use of the phone eliminated and participants motivated to lie well). The main pattern of results was replicated. We obtained an accuracy of 85% in detection of deception with 25% of false alarms.

KEYWORDS

Cold Stress Test, detection of deception, Pinocchio effect, thermography

1 | INTRODUCTION

Many studies have sought to discover common behaviors when a person is lying. However, taken together, the research suggests there is no single behavior or behaviors that, across all people or in all situations, guarantee that a person is lying. But there is evidence in the face and voice that someone is lying, particularly in high-stake lies in which the liar faces benefits for successful lying and punishment for unsuccessful lying (DePaulo et al., 2003; Ekman, 2001). For example, research has shown facial expressions of fear, distress, and disgust distinguish liars and truth tellers at over 76% accuracy (Frank & Ekman, 1997); when voice measures are added, this accuracy rises to 86.5% (Ekman, O'Sullivan, Friesen, & Scherer, 1991). The detection of lies with high accuracy and low false alarm rate is of vital importance in the fight against crime. At the same time, it could avoid accusing the innocent. Human lie-detection experts offer an average accuracy slightly above the level of chance, about 54% (Colwell, Miller, Lyons, & Miller, 2006). There are multiple devices for the detection of lies (Greely & Illes, 2007; Pollina & Ryan, 2002; Tsiamyrtzis et al., 2007), the best known being the polygraph, which offers an acceptable accuracy but also presents a series of problems (particularly presenting a high rate of false alarm and being an invasive technique; Wolpe, Foster, & Langleben, 2010).

The use of modern thermographic cameras for the detection of lies is recent (Pavlidis, Eberhardt, & Levine, 2002; Pollina & Ryan, 2002). Thermography and polygraph both focus on lying as a negative experience that produces stress on the liar (Engert et al., 2014; Panasiti et al., 2016; Pavlidis, Levine, & Baukol, 2000). Thermography's main advantage over the polygraph is that it is a contact-free technology recording the response of the autonomic nervous system. The average accuracy of lie detection with a thermal camera is 70%, but may range between 70% and 90% depending on the experimental scenario of lying (Gołaszewski, Zajac, & Widacki, 2015; Pollina et al., 2006). Its false alarm rate is also variable, between 20% and 50% (Abouelenien, Pérez-Rosas, Burzo, & Mihalcea, 2016; Warmelink et al., 2011). Moreover, accuracy in lie and truth detection with thermography does not seem to benefit clearly from the complementary or joint use with other lie detection techniques, such as physiological measures or analysis of verbal behavior (Abouelenien et al., 2016; Pollina & Ryan, 2002).

In general, the thermographic detection of lies has focused on the study of thermal changes in the face (Abouelenien et al., 2016; Gołaszewski et al., 2015; Warmelink et al., 2011). However, different authors have focused on different parts of the face, or region of interest (ROI), as a key factor to detect the lie by its thermal change: on the periorbital area (Rajoub & Zwiggeelaar, 2014; Shastri, Tsiamyrtzis, & Pavlidis, 2008), on the forehead (Zhu, Tsiamyrtzis, & Pavlidis, 2007), and on the nose (Panasiti et al., 2016). The rise in temperature in the forehead, the periorbital area, or the face in general has been associated with an arousal effect (Salazar-López et al., 2015). The thermal descent of the nose is linked to a greater sympathetic activation associated with fear, stress, lying, or guilt (Ioannou et al., 2013; Ioannou, Gallese, & Merla, 2014; Panasiti et al., 2016).

According to Panasiti et al. (2016), most experimental situations were artificial or nonecological, so that they present the opportunity to lie in the context of a card game, which they consider an ecological task (although they use few participants and do not indicate the rate of success and false alarms). They found an increased nose temperature for liars. However, a card game is a task of little use to capture suspects in relevant real situations linked to a crime committed or planning a terrorist act. We think that, in addition to looking for an ecological, real, and appropriate task to fight crime, other parts of the body may be relevant to construct the body map of the lie like the hands or torso, whose record can help to differentiate the stress of the lie. In pilot studies, we have found lying decreases the temperature of the nose and hands, regions studied in relation to stress by Pavlidis et al. (2012). In addition to registering the face, we will register the hands. Finally, we think that, although they are not completely equal, the thermal map of the lie can be potentiated under stress, given the correlation of the lie with the cognitive load (Colwell, Hiscock-Anisman, Memom, Taylor, & Prewett, 2007), so we are going to add to the scenario of the lie a situation of stress outside the lie, of a physical or social type (Engert et al., 2014), and we will also study the impact of the interview style, using the Assignment Criteria Indicative of Deception (ACID) by Colwell et al. (2007).

2 | EXPERIMENT 1: THERMAL EFFECT ON THE FACE AND HAND WHILE LYING—THE PINOCCHIO EFFECT

Pavlidis et al. (2002) have discovered in their laboratory studies that subjects submitted to a stressful situation show an infusion or accumulation of blood in the orbital muscle zone that causes an elevation of temperature in that area. The ROI is situated at the internal corner of the eye, where the blood vessels of the ophthalmic muscles converge. However, recently Panasiti et al. (2016) showed that the tip of the nose can be the most appropriate region of interest as the thermal change associated with lying is a rise in the nasal temperature (associated with sympathetic deactivation) and not a decrease of it, which would be the trait associated with the stress response. It is possible to differentiate both responses. If we discover thermography to be useful in lie detection, and with a special role of the nose, we could refer to it as "the Pinocchio effect" in honor of Walt Disney's animation and the story by Carlo Collodi.

2.1 | Method

2.1.1 | Participants

Participants in this study consisted of 20 psychology students at the University of Granada (10 male and 10 female, aged 18–26 years old). We asked all interested participants to read a brief description of this research project and provide written informed consent. After that, each participant answered a series of medical and biographical items to ensure that they were in good health and not taking medication or drugs that could interfere with the examination results. Our criteria for the selection of participants were nonsmokers, young, and healthy. The local Research Ethics Committee of CIMCYC (Mind, Brain, and Behavior Research Center) of Granada University approved this research.

2.1.2 | Equipment

We used the ThermoVision A320G Researcher Infrared Camera, which has a potential sensitivity of 0.07–30 °C of

difference between successive readings. The camera was placed on a tripod 110 cm above the floor and 60 cm from the subjects. The height was adjusted to capture the subject's whole body, only the upper body, or only the face, in frontal and lateral views, depending on the ROI required. The camera had automatic focus that was always employed to focus the image recording. The signal was recorded on a laptop with the program Researcher TermaCAMP 2.9, which allows continuous recording at eight frames per second.

2.1.3 | Procedure and settings

The experiment took place in a tested thermographic laboratory (Fernández-Cuevas et al., 2015) of CIMCYC. The experiment was carried out in a closed room of about 40 m^2, with a changing room next to it. The thermographic camera, the computer, and the experimenter were positioned in the middle of the room, facing the subject. The protocol for measuring with thermographic cameras (Ring & Ammer, 2000) demands specific preparation to obtain proper recordings. The area of the skin to be recorded must not be covered by any material. In this way, thermography is able to capture images that accurately reflect the temperature. Subjects must be at rest for between 10 and 15 min to adapt to room temperature before recording the temperature of the skin, which must be between 18 and 24 °C ($M = 22$ °C in our case). The humidity also must be controlled ($M = 50\%$ in our case). According to the procedure, when participants entered the room they were required to remain seated for 10 min on a stool in the changing room adjacent to the studio. After this, the participant entered the studio and received instructions similar to the following: "We are now going to record your face while performing different exercises or tasks … First, a static image at rest will be recorded, and then we will indicate the nature of the tasks to be performed."

Each participant was recorded in the baseline (BL) shot, which shows an initial thermogram of the whole face, then once during the task performance, and the last one after performing the task. To ensure higher quality in the ROIs, the whole sequence of movements comprising each experiment was recorded with thermography. The relevant ROIs for this project are the entire forehead, capturing both the left and the right side, and the tip of the nose, the best delimited ROI in previous studies. In addition, three regions were recorded: the eye region (area of the orbital-ocular muscle), the mouth region, and the cheeks, in line with the protocol for delimiting the ROIs of Mize and Myers (2011) and Salazar-López et al. (2015). To guarantee consistent recording of ROIs, we applied the same polygon size for each facial region in all thermograms for each participant, but adapted to each participant's particular face configuration. All participants were their own control for their ROIs; therefore, all participants were recorded in exactly the same position during all tasks, seated on a stool of variable height. Two researchers, who were blind to the purpose of the study and independent of each other, instructed in the size, shape, and position of the ROIs, and manually performed the segmentation and data collection (mean, standard deviation, maximum, minimum for each ROI) to ensure the repeatability and standardization of the ROIs. Statistical analyses were performed independently by another two researchers, each one working with one of the two data files and on the different descriptive statistics, obtaining the same general pattern of results.

In the lying task, 20 participants were asked to come to the lab after being told that they were to participate in a "top secret" research study, about which they should tell no one including their family, close friends, or partner. Once participants were situated in the thermography room and after the adaptation period, they were told that they would have 3 min to create an important alibi, and that they should fabricate a lie to tell to a significant person, like a best friend or partner of theirs, whom they would call with their own phone after the 3 min had passed. Their goal was to convince their friend or partner that the lie they were telling was true, but they were not to tell the actual truth (i.e., I am in a top secret experiment). The participants were motivated to be as convincing as possible and to create a lie that would have importance and relevance for both of them. Before and after the call, we measured each participant's anxiety level with the Spanish version of the State–Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1970/1982).

2.2 | Results

The intercoder (of ROIs) reliability (Pearson correlation) was .95, $p < .001$. Throughout the act of lying to a loved one by a phone call, the nose temperature decreased 0.7 °C on average, $F(1, 19) = 9.02$, $p < .01$ (from 29.60 °C to 28.90 °C), and the hand temperature decreased more than 1 °C, $F(1, 19) = 18.32$, $p < .01$ (from 27.20 °C to 26.10 °C). There were no significant changes in other face areas. With respect to the hand thermogram, thermal changes were observed in the fingers and the ulnar edge of the hand, as well as the inner palm. The level of state anxiety measured just after the phone call was 35.1 ($SD = 8.2$), compared to 24.0 ($SD = 7.3$) 10 min before the phone call—the difference being significant, $t = 3.55$, $p < .01$.

Of the 20 participants who performed Version 1 of the lying task, during the act of lying to a significant person with the mobile, 14 showed a decrease in nasal temperature of 1.1 (0.5) °C, $t = 5.65$, $p < .01$; three showed an increase of 0.9 (0.4) °C in the temperature of the nose, $t = 3.87$, $p < .01$. The rest of the participants did not show significant thermal

changes, which results in 70% of participants showing the Pinocchio effect.

2.3 | Discussion

This initial experiment revealed a change in the nose temperature when a person is lying, while the temperature maintained constant in the forehead. During the act of lying, it appears there is a thermal decrease in the hands and the nose of around 1 °C, possibly due to the sympathetic nervous system activation and arterial vasoconstriction, caused either by the lie or by the anxiety that lying implies. In summary, the Pinocchio effect exists, even though it is not known whether it is specific to the lie or a consequence of the anxiety caused by lying. One of our immediate interests is to dissociate the lying detection using the thermography of the anxiety thermal effect. Seventy percent of persons present a nose and hand thermal decrease.

It is possible that part of the Pinocchio effect is due to the situation of conducting a quotidian conversation by mobile phone. Some research presents a temperature change on the ears and the cheeks when a person is conducting a phone conversation, but not on the nose or on the hands (Lahiri, Bagavathiappan, Soumya, Jayakumar, & Philip, 2015). Furthermore, to control for this interference, we include a control condition in the second experiment, where participants are required to use the mobile phone. Similarly, the data could be the result of the anxiety felt by the participant when lying. To prove whether this is the cause of the thermal change, we will elicit in a new control condition a level of anxiety similar to the one produced by lying.

3 | EXPERIMENT 2: APPLYING THE COLD STRESS TEST TO THE PINOCCHIO EFFECT

Ioannou et al. (2014) suggest that in thermography it is adequate to use a control condition with a mental set opposed to the experimental condition, instead of a baseline in a rest period. Our control condition in the following experiment will use the mobile phone, and so it will have a similar level of anxiety and an opposed mental disposition (truth-telling condition). In this second experiment, the CST (Antonio-Rubio et al., 2015; Lovallo, 1975) is used, which activates the autonomic nervous system. Thus, we expect to potentiate the Pinocchio effect, considering that homeostasis processes will be originated (thermal recovery after the vasoconstriction due to the immersion in cold water), as defended by Ioannou et al. (2014), who affirm that it is more appropriate to use a baseline condition where emotions are generated in the participant (in this case, pain or stress). They rely on the statement that the autonomic nervous system runs on two interlinked opposing subdivisions. Therefore, we expect to potentiate the discriminatory potential of thermography in lying detection.

3.1 | Method

3.1.1 | Participants

Thirty-one (24 female, average age 21.5, range 18–36) undergraduate students volunteered to take part in this study. They received course credit for their participation. All participants signed a consent form and were informed of the method. We also obtained ethical permission from our research group (SEJ-497) in CIMCYC for this research. All participants reported an absence of cerebral damage, and there was no clinical evidence of drug abuse during the course of the study. Additionally, no participants reported a mental disorder. Our criteria for participant selection was the same as in Experiment 1.

3.1.2 | Equipment

The same equipment was used as in Experiment 1, adding a container with cold water to apply the CST.

3.1.3 | Procedure and settings

This experiment was carried out in the same room as in Experiment 1, fulfilling the new measurement protocol with a thermographic camera. The room conditions were the same, maintaining intact the temperature, the humidity, and the waiting time before beginning the task. The instructions were explained to the participant, and we immediately recorded a baseline, including not just the face, but also the hand temperature, both in the palm and on the back.

In this case, we recorded two ROIs principally: the tip of the nose and the tip of the finger of the dominant hand (dorsal part). The ROI was the dorsal part of the third finger, specifically the distal phalanx (Antonio-Rubio et al., 2015). We followed the same protocol as in Experiment 1 to ensure the repeatability and standardization of the ROIs.

The CST consisted of immersing the naked dominant hand (without wearing gloves) in a bucket of cold water (3 ± 1 °C) for 2 min. Subsequently, we recorded the thermal recovery of the hand during 6 min, exactly as has been done in previous research (Antonio-Rubio et al., 2015; Bharara, Viswanathan, & Cobb, 2008; Chlebicka, Matusiak, Baran, & Szepietowski, 2012; Lovallo, 1975; Pauling, Flower, Shipley, Harris, & McHugh, 2011; Stefańczyk, Woźniakowski, Pietrzak, Majos, & Grzelak, 2007). See Figure 1.

Our main hypothesis is that lying, due to the Pinocchio effect (Experiment 1), generates vasoconstriction in both the

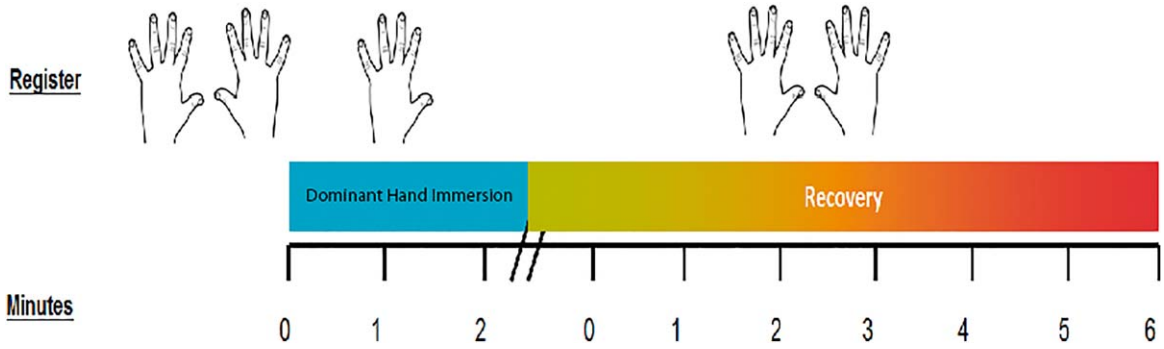

FIGURE 1 A scheme of the Cold Stress Test conditions

hand and the nose; and therefore it will increase the time needed for the thermal recovery of the hand after applying the CST in relation to the baseline condition, and there will be no rebound thermal effect, habitual for the nose (this rebound effect consists of an increase in the face temperature after the CST over its baseline or temperature previous to the immersion; Engert et al., 2014). For the truth-telling condition (see below), we expect the thermal recovery not to be affected if the Pinocchio effect is not due to the anxiety level involved. In the opposite case, since in the truth-telling condition it caused a similar level of anxiety to that in the lying condition, we also expect a lower thermal recovery than in the baseline condition.

3.1.4 | Experimental condition: Lying

We informed the participants that they were participating in a study denominated top secret (the same as Experiment 1). When the 3 min to elaborate an important lie were finished, we applied the CST, asking the participant to immerse the dominant hand, up to the wrist, in the bucket of cold water for 2 min. Finally, when the 2 min of immersion were finished, the participants called by mobile phone the chosen person to tell them the lie they had constructed. This phone call was to last 6 min, the same duration that is applied frequently in the CST to measure the thermal recovery of the hand. The participant should hold the mobile phone with the nondominant hand, and show to the thermographic camera the dorsal dominant hand, with the objective of recording the thermal recovery. Before the phone call and after completion, the participants proceeded to complete the STAI test to obtain a measure of the anxiety felt by the participant after the phone call. The participants who either were not believed by the interlocutor, executed the lie in an unconvincing way (with laughs, doubts, or long silences, for example), or whose phone call did not reach the 6 min were eliminated from the research data.

3.1.5 | Control Condition 1: Truth telling

Traditionally, the rest condition of the participant has been taken as a baseline condition. In the case with the CST, the baseline condition of thermal recovery would be to carry out this task without calling anyone or viewing the images. We decided to use the opposite condition (truth telling) as the control, following Ioannou et al. (2014), who affirm that it is better to use as a baseline condition an emotion (or mental set) that is generated, as opposed to one that is measured.

In the control condition, participants completed the waiting time in the experimental room, as in the other conditions. Then, we applied the CST (as we have described in the previous condition). After that, the participant called a person important to them and described to the last detail the images that were appearing automatically on the screen, with a duration of 30 s each, for 6 min. These images were selected from the IAPS battery; specifically, we selected the negative valence and high arousal images used by Salazar-López et al. (2015) in her experiment 1 (Set 4). For instance, we selected images of cadavers, mutilated bodies, and violent acts (numbers 1525, 9265, 3015, 9433), whose average (*SD*) was 1.70 (1.10) for the valence dimension, and 7.35 (1.80) for the arousal dimension. They produced a state anxiety of 32.97 after observing these images in our pilot study, and similar results of state anxiety in other studies where it has been used (Limonero, Fernández-Castro, Soler-Oritja, Álvarez-Moleiro, 2015; Pacheco-Unguetti, Acosta, Callejas, & Lupiañez, 2010). The objective was to compare the thermogram of the participant when telling the truth and when lying, under a similar level of anxiety in both cases, as would be confirmed with the state scale of the STAI before and after the phone call. This permitted us to confirm that, in the case that there is a different thermal recovery in the lying condition, it can be attributed neither to an anxiety effect, nor to the mobile phone use.

3.1.6 | Control Condition 2: Baseline

We also used as control Condition 2 the thermal recovery of the participants after the CST without calling anyone or viewing the images, or experiencing more anxiety than generated by the CST. In this last condition, after the waiting time in the experimental room, we applied the CST. First, the participant immersed the dominant hand in cold water for

TABLE 1 Model of the lies from Experiment 1 and 2

Lie content	Receiver
I want to abandon my university study.	Mother/father
I have failed my last exam.	Mother/father
I have met with my ex-boyfriend again.	Friend
I have had a car accident while driving to the faculty.	Father
We are moving to France, my mother has been offered a job there.	Friend
I have missed the deadline for paying the registration fee, so I am not allowed to do the exams.	Friend
I have argued with a flatmate, so I am moving to another flat.	Mother
My change purse has been stolen in the supermarket.	Friend
My teacher has ejected me from the classroom.	Friend
I have been injured, so I cannot play in the next football match.	Friend
My jacket has been stolen at the faculty's cafeteria.	Father

2 min, and then the dorsal part of both hands was recorded for 6 min.

In summary, the participants attended the laboratory on three occasions: the lying session (by phone call after CST), the truth-telling session or control condition (describing the disagreeable images by phone call after CST), and the CST session or baseline (where participants neither lied, nor called, nor viewed the images). The order of these three sessions was random for each participant. Each session was separated from the next by a minimum of 3 days. Before and after each session, state-anxiety was measured using the STAI.

3.2 | Results

Table 1 shows the type of lies invented and to whom they were directed.

The percentage of people rejected for not following the instructions was 20.5% (8 out of 39 participants were eliminated). The intercoder of ROI reliability was .84, $p < .001$.

Regarding the tip of the finger, we observed a drastic decrease of its temperature from around 28 °C to 14 °C after applying the CST in every condition, due to the cold. After that, concerning the thermal recovery of the hand, we observed that it was slower when the participant was lying (it reached 18 °C in 3 min), while it increased up to 21.75 °C when the participant was either telling the truth (truth-telling condition) or doing nothing (baseline).

The interaction Condition × Time was significant for the finger, $F(8, 240) = 3.73$, $p < .0004$. See Figure 2.

If we compare the baseline condition of the CST (without a concurrent task) with the lying condition, the difference in the thermal recovery from minute zero (T0) to the sixth minute (T6) was significant, $F(4, 120) = 4.57$, $p < .0005$, with the thermal difference between both conditions only significant for the fourth minute (T4), $F(1, 30) = 5.75$, $p < .0228$, and the sixth minute (T6), $F(1, 30) = 6.31$, $p < .0176$.

If we compare the lying condition with the truth-telling condition, the thermal recovery was different for both groups, $F(4, 120) = 6.09$, $p < .0014$. The temperature was different for both conditions only for T6, $F(1, 30) = 5.09$, $p < .0420$.

However, there were no differences in the thermal recovery of the finger between the truth-telling condition and baseline of the CST condition, $F(4, 120) = 2.19$, $p < .0737$. Given that the difference was marginal, we analyzed it for each temporal moment, and the finger temperature was only

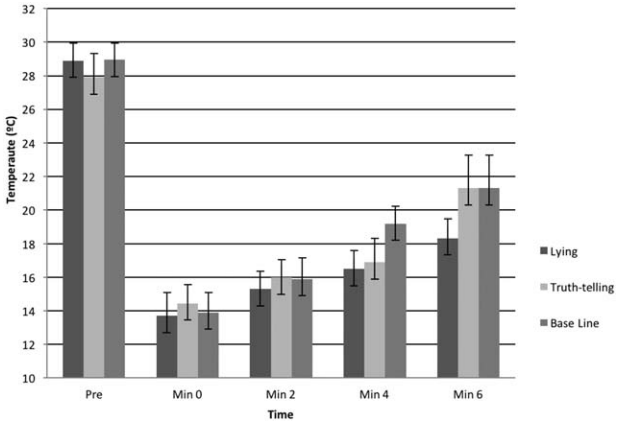

FIGURE 2 Temperature of the fingertip over time while performing the task of each condition (Experiment 2). Pre = before immersion of the hand

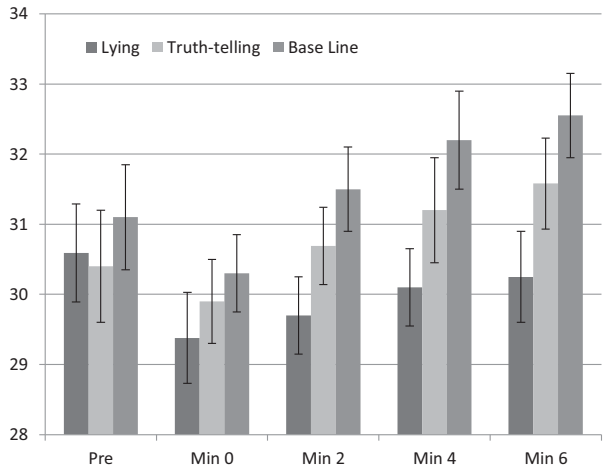

FIGURE 3 Temperature of the nose over time while performing the task of each condition (Experiment 2). Pre = before immersion of the hand

different between both conditions at T4, $F(1, 30) = 4.17$, $p < .0499$.

In summary, thermal recovery in the lying condition was lower than in the other two conditions. Nevertheless, until the fourth minute, recovery in the lying and truth-telling conditions was identical. In both cases, the recovery began to be delayed at the fourth minute with respect to the baseline condition; but the delay disappeared for the truth-telling condition at the sixth minute, while it remained for the lying condition. Regarding the nose, we observed a rebound effect in the truth-telling and baseline conditions when we applied the CST; this rebound did not appear in the lying condition. We relied on a previous average temperature of 31 °C for the baseline condition and 30 °C for the truth-telling and lying conditions—an insignificant difference.

A thermal decrease happened in the tip of the nose when the participant immersed the hand in the water with a temperature of between 0.6 °C and 1 °C. When the participant removed the hand and started the experimental task, the thermal increase in the nose became quite pronounced (rebound effect), reaching 32.5 °C in the baseline condition and 31.6 °C in the truth-telling condition. In contrast, in the lying condition, thermal recovery of the nose was lower (30.2 °C in the sixth minute), annulling the thermal rebound we observed in the other conditions; see Figure 3. Although only one hand was immersed, we did not find any lateralization effects on the facial regions considered. The thermal recovery of the nose was different depending on the condition, $F(8, 240) = 7.28$, $p < .0001$.

If we compare the lying condition with the baseline of the CST, the thermal recovery was different, $F(4, 120) = 13.34$, $p < .0001$; the temperature being different between both conditions in the second minute, $F(1, 30) = 8.33$, $p < .0071$; in the fourth minute, $F(1, 30) = 9.44$, $p < .0044$; and in the sixth minute, $F(1, 30) = 11.38$, $p < .002$. There was only a rebound effect, measured as the difference between the nose temperature previous to the immersion (BL) and the nose temperature, in the sixth minute (T6-BL), for the baseline condition of the CST, $F(1, 30) = 17.77$, $p < .0002$.

Comparing the truth-telling condition with the lying condition, thermal recovery after the immersion was again different for both conditions, $F(4, 120) = 7.75$, $p < .0001$. A significant difference in temperature existed at the sixth minute, $F(1, 30) = 8.54$, $p < .0066$.

The rebound effect for the truth-telling condition was significant, $F(1, 30) = 10.98$, $p < .0024$. However, when comparing both control conditions, there were no significant differences in the thermal recovery of the nose, $F(4, 120) = 1.21$, $p < .3095$. In summary, a rebound effect of the thermal recovery of the nose happened in the control conditions but did not appear in the experimental condition.

The data from the state scale of the STAI for the three conditions at the beginning of the session were similar: 15 ($SD = 2$), 15 ($SD = 4$), and 13 ($SD = 3$) respectively. However, at the end of the session, anxiety states were 20.5 ($SD = 4.9$) for the baseline condition, 31.8 (SD = 6.1) for the truth-telling condition, and 33.0 ($SD = 7.3$) for the lying condition. This was the only significant difference between the baseline condition and the other two conditions, $t = 3.23$, $p < .01$. That is, the level of state-anxiety in both the lying condition and the truth-telling condition was similar, as expected.

If we compare the lying condition and the truth-telling condition, we obtain a discrimination superior to 80% for both the finger and the nose in the sixth minute (area under the curve [AUC] = 0.890, 95% CI, 0.790–0.968; AUC = 0.828, 95% CI, 0.690–0.958, respectively).

4 | EXPERIMENT 3: A REPLICATION OF THE PINOCCHIO EFFECT WITH THE CST

We attempted to replicate the two main results of the experiment. In addition, to determine whether our results are generalizable beyond a mock scenario, we substituted the type of lie with a biographical lie planned and motivated previously (see Method), since self-gain and other gains are fundamental mediators of lying (DePaulo et al., 2003; Ekman, 2001), and we asked vía a questionnaire to what extent s/he was motivated to do well during the study (on a 7-point Likert Scale ranging from 1 = *not at all* to 7 = *very much*; Vrij, Granhag, Mann, & Leal, 2011). To avoid the interference caused by the use of the phone in the detection of lying, we eliminated it and used the evaluation by blind experimenters and experts in lie detection with the ACID interview style

system (Colwell et al., 2007). We measured the anxiety of trait and state at the beginning and end of the session to see how it evolved. In this new experimental situation, the uncooled hand is free, which was also recorded, so that we have three thermal points of analysis: the tip of the nose, the back of the middle finger of the cooled hand, and the back of the middle finger of the uncooled hand.

4.1 | Method

4.1.1 | Participants

Twenty (10 female, average age of 23.5, range 20–40) undergraduate students volunteered to take part in this study under the same selection criteria as in Experiment 2.

4.1.2 | Equipment

The equipment was the same as in Experiment 2.

4.1.3 | Procedure and settings

This experiment was carried out in the same room and conditions as in Experiment 2. In this case, we principally recorded three ROIs: the tip of the nose, the tip of the finger of the dominant hand (dorsal part), and the tip of the finger of the nondominant hand (dorsal part).

We left the CST in direct contact with the participant's naked hand for 2 min at 2 °C ± 1 °C. After that time had elapsed, we removed the CST. Subsequently, we recorded the thermal recovery of the hand during 6 min, exactly as in our previous experiment.

4.1.4 | Description of the participant's task

Some days before the thermal sessions, participants were asked to write their biography over the previous 5 years before they arrived here (to study psychology and decided to join the course of psychology of the lie) supplying a certain level of detail on an A4 folio with single spacing and font size 12 Roman Courier. Then, on the next day of class, each participant was given the anonymous biographical story of another student in a random way and was informed that this was his lie. They were to study it. Finally, they were advised to go to two sessions, separated by four days, to the CIMCYC thermography laboratory, where they would tell to a human expert in detecting lies either his story (true condition) or the story of his partner as though it was their own (lie condition), according to a code that they also received at random. This code indicated when (whether in Session 1 or Session 2) they were going to lie or tell the truth.

The codes could be truth1–truth2 (tell the truth in Session 1 and tell the truth in Session 2), lie1–lie2, truth1–lie2, lie1–truth2. The codes truth1–truth2 and lie1–lie2 were added to make the expert's task more complex, but only the data of the 20 subjects who went through the conditions tell the truth or lie intrasubject were analyzed. At the end of each session, the expert wrote his answer, if he or she thought the participant had lied or told the truth, and the participant showed his code. The expert in detecting lies would be different in each session. If the experts' answers at the end of the two sessions did not coincide with the participant's code for lie (error in detection of deception), the participant passed the test and received an extra point. Otherwise, he or she did not pass the test and lost a point in his grade. After this, the winners were congratulated in public by the teacher and the rest of the class.

4.1.5 | Interview script

All participant responses were recorded in audio. During the interview, the blind experimenter could ask questions following the simplified interview script from table 1 of Colwell et al. (2007) of the ACID system. Specifically the structure of the interview was as follows: (a) Baseline and rapport. Both interviewers adopted a cooperative mode of interaction to avoid additional sources of stress to the participant. (b) The CST was placed in the participant's hand (maximum duration of 2 min). (c) The CST was withdrawn, and the participant was asked for a free recall with an approximate duration of 3 min. Next, the participant was asked for another recall with an approximate duration of 3 min, this time in reverse order (i.e., from the end to the starting point).

4.1.6 | Thermograms' mode of evaluation

Three thermal videos were recorded, one for each step of the interview. To simplify the analysis of each participant, only the baseline temperature (BL) (Step 1) in T0 (minute zero of the recovery, which coincides with the start of step (c) of the interview) and T6 (minute six of the recovery, after having completed the reverse order recall).

To compute the classification criteria as lie or truth for changes in the temperature of the nose, the cooled hand, and the uncooled hand, we proceeded according to our previous results. For each key registration point, we concluded that a participant lied if he or she did not show a nose-bounce effect (the temperature in T6 was less than or equal to the BL). If it did not show uncooled hand recovery (T6 ≤ T0) and if the thermal recovery of the hand cooled at T6 was less than 40%, as occurred in Experiment 2 (which equates to a recovery below 6 °C in Experiment 2), the participant was classified as a liar. If the participant met only one or none, he

or she was considered to be truthful. In this way, we hoped to increase accuracy and decrease false alarms. This method also confirms the agreement between experts and the agreement between experts and the results of the analysis of thermograms.

4.2 | Results

The intercoder (of ROIs) reliability was .95, $p < .001$. The participants reported being very motivated during the task ($M = 6.55$, $SD = 0.45$). In the group analysis of the data, for the nose we obtained a significant interaction between the type of response (truth or lie) and the time variable (BL, T0, and T6), $F(2, 38) = 11.95$, $p < .001$. The rebound effect (difference between BL and T6) for the tell-the-truth condition was significant, $F(1, 19) = 20.89$, $p < .001$; but not for the lying condition, $F(1, 19) = 0.02$, $p < .88$. The mean temperature for the true condition in BL, T0, and T6 was 30.2 °C, 30.1 °C, and 32.8 °C, respectively. The mean temperature for the lying condition in BL, T0, and T6 was 29.9 °C, 29.1 °C, 29.5 °C, respectively. Although only one hand was cooled, we did not find any lateralization effects on the facial regions considered.

For the cooled hand, the interaction between the response type and time was also significant, $F(2, 38) = 4.20$, $p < .02$. The recovery was greater in T6 for the true condition than for the lie condition, $F(1, 19) = 5.80$, $p < .02$. The mean temperature for the true condition in BL, T0, and T6 was 28 °C, 17 °C, 22 °C, respectively. The mean temperature for the lying condition in BL, T0, and T6 was 29 °C, 17.6 °C, 19 °C, respectively.

For the uncooled hand, the interaction between the response type and time was also significant, $F(2, 38) = 8.70$, $p < .001$. The recovery was greater in T6 for the true condition than for the lie condition, $F(1, 19) = 6.51$, $p < .01$. The mean temperature for the true condition in BL, T0, and T6 was 28.7 °C, 29 °C, 30.5 °C, respectively. The mean temperature for the lying condition in BL, T0, and T6 was 29 °C, 28.4 °C, 28.3 °C, respectively.

The agreement between experts was $rxy = .80$, $p < .001$. The accuracy in deception detection for Expert 1 was 65% and 35% of false alarms. For Expert 2, accuracy was 60% and 30% of false alarms. The agreement between the experts and the thermographic analysis was $rxy = .72$, $p < .001$. For the tip of the nose, applying the criterion of concluding that the participant lied if he or she showed a rebound effect equal to or less than zero, we obtained a percentage of successes of 75% and a false alarm rate of 20%. For the cooled hand, with the criterion of concluding that the participant lied with a thermal recovery less than 40%, the success rate was 90% and the false alarm rate was 45%. For the uncooled hand, with the criterion to conclude that the participant lied if he or she showed a thermal recovery equal to or less than zero, the success rate was 80% and the false alarm rate was 30%. When combining the three criteria, with the rule of obtaining the lie conclusion if the participant had been classified as a liar in at least two of them, the success rate was 85% and the false alarm rate was 25%.

4.2.1 | Anxiety

For the truth, state anxiety rose from the baseline, 13 (4), by telling the true story with cognitive overload, backward, 18 (6), $F(1, 19) = 5.66$, $p < .05$.

For a lie, state anxiety rose by lying with cognitive overload, with respect to baseline, 23 (7), $F(1, 19) = 8.93$, $p < .01$. Therefore, lying about your biography raises state anxiety about telling the truth only marginally, $F(1, 19) = 4.37$, $p < .06$.

Regarding the group trait anxiety, 25 (12), we obtained a nonsignificant correlation with the percentage of thermal recovery of the cooled hand at T6, $rxy = -.38$, $p > .05$.

5 | DISCUSSION AND CONCLUSION

We observe, after the use of the CST, that a thermal recovery of the hand of around 60% in 6 min and a significant rebound effect in the nose of beyond 1.5 °C exists when the person is being sincere as well as in the baseline condition without a concurrent task. These effects are annulled when the person is lying, causing a condition where the thermal recovery of the hand is lower, of around 30%, and there is no rebound effect (-0.3 °C) in the nose temperature. We suppose that this lower thermal recovery and this absence of rebound effect is due to the vasoconstriction generated because of the act of lying or Pinocchio effect, and it cannot be attributed to an anxiety effect, since the state anxiety in the truth-telling group was similar (Experiment 2 and 3) and the interaction with trait anxiety was nonsignificant (Experiment 3). Thermography discriminative capacity for the lie is above 85%.

A future option would be to use the Cold Pressor Arm Wrap (Porcelli, 2014) or the Trier Social Stress Test, which produces a thermal pattern similar to CST in the different phases of the test (Engert et al., 2014) to confirm that induced stress increases the autonomic response to detect disappointment, so this methodology would be applicable in ecological settings, without losing the contact-free and non-invasive advantages of thermography.

However, we should keep investigating whether the thermal changes provoked when a person is lying are due either to the act of lying itself, or to other emotions inherent in the act of lying. Nevertheless, we need to investigate the role of other factors such as mental workload, empathy, type of lie,

interviewer's attitude (cooperative or accusatory), and type of interview. As well, we need to verify empirically what multimodal approach to lie detection offers better results. There may be other deception detection techniques that combine better with thermography to increase accuracy and reduce false alarms.

ACKNOWLEDGMENTS

This research was supported by a FONDECYT grant (project 1160368) from CONICYT Chile. This article includes part of the thesis of Ph.D. student A. Moliné from the Mind, Brain, and Behavior Research Center, University of Granada.

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How to cite this article: Moliné A, Gálvez-García G, Fernández-Gómez J, et al. The Pinocchio effect and the Cold Stress Test: Lies and thermography. *Psychophysiology*. 2017;00:1–11. https://doi.org/10.1111/psyp.12956