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Relative Contribution of Odour Intensity and Valence to Moral Decisions

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Abstract
Meta-analytic evidence showed that the chemical senses affect moral decisions. However, how odours impact on morality is currently unclear. Through a set of three studies, we assess whether and how odour intensity biases moral choices (Study 1a), its psychophysiological responses (Study 1b), as well as the behavioural and psychophysiological effects of odour valence on moral choices (Study 2). Study 1a suggests that the presence of an odour plays a role in shaping moral choice. Study 1b reveals that of two iso-pleasant versions of the same neutral odour, only the one presented sub-threshold (vs. supra-threshold) favours deontological moral choices, those based on the principle of not harming others even when such harm provides benefits. As expected, this odour intensity effect is tracked by skin conductance responses, whereas no difference in cardiac activity – proxy for the valence dimension – is revealed. Study 2 suggests that the same neutral odour presented sub-threshold increases deontological choices even when compared to iso-intense ambiguous odour, perceived as pleasant or unpleasant by half of the participants, respectively. Skin conductance responses, as expected, track odour pleasantness, but cardiac activity fails to do so. Results are discussed in the context of mechanisms alternative to disgust induction underlying moral choices.

Keywords
Odour intensity, odour valence, moral decision-making, psychophysiology

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Introduction

The chemical senses have proven to be ideal model systems to disentangle the role of arousal and valence (Anderson et al., 2003; Winston, Gottfried, Kilner, & Dolan, 2005), the two core dimensions of affective experiences (e.g., Lang, 1995). Indeed, odours (as well as flavours) can be described based on their intensity (a proxy for arousal; Bensafi et al., 2002) and – perhaps more often – based on their hedonic value (or valence; Yeshurun & Sobel, 2010). Beyond the modulation of subjective experiences, odour intensity and valence induce changes in a variety of physiological and behavioural processes. For instance, Bensafi et al. (2002) report that skin conductance variations track odour intensity, heart rate variations track odour pleasantness and the two indices highly correlate. Furthermore, odour intensity judgements affect cross-modal perception (i.e., color lightness, Kemp & Gilbert, 1997; sweetness, Stevenson, Boakes, & Prescott, 1998), whereas odour valence is able to promote mood changes (Chen & Haviland-Jones, 1999).

The study of the effects of odour intensity and valence has mostly focused on perceptual issues, and only recently it has moved towards the impact that such olfactory dimensions have on higher cognitive functions (Mainland, Lundström, Reisert, & Lowe, 2014; Yeshurun & Sobel, 2010). Few attempts have been recently produced in the context of decision-making processes. In real life situations, intensity-controlled, pleasant ambient odours promote positive emotions in consumers and bias their decision-making processes towards spending (Chebat & Michon, 2003). In the lab, Bonini et al. (2011) revealed that male participants exposed to a disgusting odour increased cooperation during the Ultimatum Game, suggesting that the disgust felt for poor offers was misattributed to the odour, rather than to the offer itself. As the meta-analysis by Landy and Goodwin (2015) suggests, the most interesting attempts at evaluating chemosensory effects on decision processes refer to the moral domain. Their analysis showed that olfactory (and gustatory) induction of disgust amplifies its effects on moral behaviour more that the induction of disgust prompted through videos or images. However, the number of studies inducing disgust through chemosensory stimuli is disproportionately smaller (3 published studies) than the number of studies including visual induction of disgust (12 published studies). Despite this asymmetry, the chemosensory induction of disgust (gustatory and olfactory) produced a stronger amplification effect (Cohen's $d = .37$) on moral choice than visual induction (Cohen's $d = .13$) or than the total amplification effect irrespective of the modality (Cohen's $d = .11$). With specific reference to the olfactory modulation of moral behaviours, Inbar, Pizarro, and Bloom (2012) reported that a disgusting odour (vs. no odour) lead participants to evaluate gay men more negatively, whereas both Schnall, Haidt, Clore, and Jordan (2008) and Ugazio, Lamm, and Singer (2012) used commercially available "fart spray" to prime disgust in participants while they rated four vignettes requiring either a moral judgment (Schnall et al., 2008) or while they judged the permissibility of some moral scenarios (Ugazio et al., 2012). In Schnall et al. (2008), authors assigned participants to one of three olfactory conditions (no vs. four vs. eight sprays applied). After they completed the task, they were asked to rate how disgusted they felt and whether they were consciously aware of the presence of the unpleasant odour. Participants were significantly more disgusted in the strong odour condition than in the other two conditions, and the more participants experienced olfactory-triggered disgust, the more severely they judged the proposed vignettes (Schnall et al., 2008). Ugazio et al. (2012) used the same procedure as in Schnall et al. (2008), but with less intense odour stimulations (only two sprays applied), which led to the disappearance of disgust-attributed severity in the moral judgements.

Taking a chemosensory standpoint, some considerations are in order. First, the comparison of Schnall et al. (2008) results with Ugazio et al. (2012) suggests an interesting possible modulation of moral behaviour based on odour intensity, aspect linked to the awareness of the odour (Smeets, Schifferstein, Boelema, & Lensvelt-Mulders, 2008). Indeed, Schnall et al. (2008) showed significant modulation of moral behaviour when participants were exposed to an odour that was clearly perceivable (especially in the strongest condition – eight sprays), whereas Ugazio et al. (2012) failed to find such effect with lower intensities of the odour (two sprays). Second, the use of disgusting odours based on the emotional congruency with moral disgust promoted the testing of negative odours only (e.g., Schnall et al., 2008; Ugazio et al., 2012). As revealed by Bensafi et al. (2002), the interdependent nature of odour intensity and odour pleasantness is reflected at the level of judgments and physiological correlates. Indeed, greater concentrations of one odour, irrespective of their initial pleasantness judgment, are perceived as less pleasant and are associated with increased peripheral sympathetic and reduced cardiac parasympathetic activity. Altogether this evidence calls for an extension of the exploration of the olfactory effects on moral behaviours that goes beyond negative odours. Moreover, studies that encompass neutral and pleasant odours are needed in order to disentangle the role played by valence, especially in the context of decisions modulated by multimodal stimulations. Third, the evaluation of the odour stimuli, their delivery (e.g., Lundström, Gordon, Alden, Boesveldt, & Albrecht, 2010) and the inclusion/exclusion criteria of participants (Boesveldt et al., 2011), an aspect generally neglected in the moral literature, should be promoted as to reduce potential confounding effects.

In order to shed light on the effects that arousal and valence of olfactory stimuli might have on moral behaviours, we designed three studies in which normosmic participants were asked to perform a moral decision-making task in the presence of different odour conditions. As in typical moral decision-making tasks, we present moral dilemmas, hypothetical short stories that offer two morally conflicting alternatives among which a decision maker is expected to choose (see also Cecchetto, Rumiati, & Parma, submitted). According to the most influential theory (the dual process model; e.g., Greene, 2009), moral choices are driven by the interaction between two competing processing systems, mediated by partially dissociable neural networks. First, a fast, automatic emotional system is expected to play a central role in the expression of deontological choices, based on the idea that an individual's moral principle should not be infringed, even when the welfare of a greater number of people is at stake. However, such intuitive moral choice can be overridden by cognitive (executive) processes which favour, instead, the expression of utilitarian responses grounded on a cost–benefit analysis tailored to reduce the overall harm across the available options. In other words, utilitarian choices require more cognitive resources (Greene, Morelli, Lowenberg, Nystrom, & Cohen, 2008; Van Dillen, van der Wal, & van den Bos, 2012) to contrast deontological responses, yet the difficulties emerging in the process are associated with greater negative emotional reactions linked to the sense of responsibility for an immoral act (e.g., killing a person; Moretto, Ladavas, Mattioli, & Di Pellegrino, 2009). Additionally, the modulation of the emotional reactions triggered by moral dilemmas can be associated to the features of the moral dilemmas. The most studied feature refers to the degree of personal involvement in the immoral act. The popular *Trolley* dilemma (Foot, 1967) is an example of impersonal dilemmas. In this dilemma, a runaway trolley is about to run over and kill five people. To save the group of five, the decision maker can hit a switch that will turn the trolley onto a side track. This act will cause the death of the person standing on the track. The *Footbridge* dilemma (Thomson, 1976), instead, is an example of personal dilemma, in which participants can save the five by pushing a big man off an overpass onto the track below: The man will die but the five people will survive. In virtue of their stronger emotional content, personal dilemmas tend to elicit more deontological choices than impersonal dilemmas (Greene et al., 2009; Greene et al., 2008; Greene, Nystrom, Engell, Darley, & Cohen, 2004; Koenigs et al., 2007).

In light of the scarcity of evidence on the effects produced by olfactory stimuli on moral choices (Inbar et al., 2012; Schnall et al., 2008; Ugazio et al., 2012), we set out to test a series of hypotheses on whether and how odour intensity and odour valence modulate moral choices.

In Study 1a and Study 1b, we tested the role of odour intensity across iso-pleasant stimuli in impacting moral choice. Specifically, we assessed whether the supra-threshold vs. sub-threshold versions of a neutral odour will comparably modulate moral choice tendencies, with respect to a no-odour condition. Three hypotheses have been proposed. First, a neutral odour condition, irrespective of its intensity, might increase deontological responses due to the activation of limbic areas through olfaction (Zald & Pardo, 1997). Indeed, the olfactory and limbic systems share common substrates (e.g., amygdala, insula, anterior cyngulate cortex and orbitofrontal cortex; Soudry, Lemogne, Malinvaud, Consoli, & Bonfils, 2011) and, in particular, a previous study has showed that odor intensity is associated with amygdala activation (Anderson et al., 2003). Second, if only the supra-threshold odour condition produces an increase of deontological responses, compared to the sub-threshold odour, we could argue that an olfactory stimulus needs to be presented in high concentration to affect moral behaviour. The pleasantness evaluation should allow us to ascertain whether or not such higher concentration is responsible for inducing possible unpleasantness/disgusting reactions. Third, we hypothesize that the eventual selective increases of the number of deontological responses in sub-threshold condition is caused by insufficient sensory inputs that, as such, do not trigger the strategic control (Li et al., 2007). In other words, lower concentrations of an olfactory stimulus, possibly by the effect of lack of awareness, may be key to the emergence of deontological moral choices.

In Study 1b, we tried to conceptually replicate the above study in an independent group of participants and, additionally, we collected psychophysiological responses to implicitly assess the intensity and valence effects of olfactory stimuli during moral decisions. We foresee that, beyond the arousal induced by the processing of the moral dilemma, odour intensity will be tracked by skin conductance (SCR) measurements, showing an increased activity in the supra-threshold odour condition compared to sub-threshold and no odour conditions, respectively. This effect should be evident for both utilitarian (more arousing) and deontological choices (less arousing, Moretto et al., 2009). Given that odour valence is expected to be equivalent between sub- and supra-threshold odour conditions, we do not foresee modulations at the level of instantaneous heart rate (IHR; Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000), an implicit index of valence (Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley, Greenwald, & Hamm, 1993; Palomba, Angrilli, & Mini, 1997). In line with previous literature on pleasant and unpleasant stimuli (Palomba et al., 2000), we foresee a greater deceleration of IHR for deontological rather than utilitarian choices.

In Study 2, we will test the role of valence in iso-intense olfactory stimuli. We will compare the modulatory effect of neutral, pleasant and unpleasant odours on moral tendencies. Since it has been shown that an ambiguous odour can be perceived as either pleasant or unpleasant (de Araujo, Rolls, Velazco, Margot, & Cayeux, 2005), we presented a group of participants with the same ambiguous odour (butyric acid) and we then split them in two groups, based on their reported pleasantness evaluation. Following previous studies on morality and induced affective states (Pastötter, Gleixner, Neuhauser, & Bäuml, 2013; Schnall et al., 2008; Valdesolo & DeSteno, 2006; Youssef et al., 2012b), we outline three alternative hypotheses. The first hypothesis posits that odour valence is not critical to moral choice. If so, the presence of an odour, irrespective of its valence, may increase deontological choices as compared to the no odour condition. The latter two hypotheses suggest that odour valence plays a role in moral choice. In one case, we hypothesize a generalized effect of valence (as in Seubert et al., 2010), emerging as an increase of deontological responses for the pleasant and unpleasant odour, as compared to the neutral and no odour conditions. Alternatively, if disgust is critical to moral decisions, as suggested elsewhere (e.g., Chapman, Kim, Susskind, & Anderson, 2009; Rozin, Haidt, & Fincher, 2009), we expect an inverse relationship between odour pleasantness and the increment in deontological choices (e.g., the less pleasant the odour, the more deontological choices). At the psychophysiological level, we expect SCR to track the effects of odour valence (Bradley, 2009) and also to reflect decreased arousal in association with deontological moral choices. With respect to the IHR, we foresee the unpleasant odour to produce the maximal decrease in IHR, as compared to the neutral and pleasant odour, respectively.

Finally, previous literature has shown that moral choices are modulated also by individual variability in emotion recognition (Koven, 2011; Patil & Silani, 2014a, 2014b), sensitivity to disgust (Choe & Min, 2011; Schnall et al., 2008; Ugazio et al., 2012), autistic traits (Buon et al., 2013; Moran et al., 2011) and anxiety (Starcke, Wolf, Markowitsch, & Brand, 2008; Youssef et al., 2012a). To control for this variability, we will ask participants to complete questionnaires that measure these individual traits. Moreover, since our hypothesis is that the attention that people direct to odours could modulate the effects that odours might have on moral choices, our participants also performed the questionnaire on the awarness of odour in the environment (Smeets et al., 2008).

Study 1a – Does Odour Intensity Affect Moral Choice?

Material and Methods

Participants. Seventeen participants were included in Study 1a, based on their eligibility according to the following exclusion criteria: history of neurological or psychiatric disorders, being an active smoker, using psychopharmacological substances or other systemic medications, having experienced a head trauma leading to unconsciousness, score less than 10 at the Sniffin Sticks Identification test (Hummel, Sekinger, Wolf, Pauli, & Kobal, 1997). Please refer to Table 1 for details on the participants' characteristics. The local University Ethics Committee approved all studies, which were in accordance with the Declaration of Helsinki, and informed written consent was obtained from each participant.

Self-report questionnaires. The following *paper and pencil* questionnaires were administered to assess interpersonal characteristics that have shown to affect moral decisions: Bermond–Vorst Alexithymia Questionnaire, form B (BVAQ-B; Bermond & Oosterveld, 1994) was used to assess Alexithymia; Disgust Scale (DS; Rozin, Haidt, McCauley, Dunlop, & Ashmore, 1999) was used as measure of the individual differences in sensitivity to disgust; the *Trait scale* of the State Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Ree, French, MacLeod, & Locke, 2008) was used to assess anxiety at trait level; the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) was used to measure the degree of presence of traits associated with the autism spectrum; the Odour Awareness Scale (OAS; Smeets et al., 2008) was used to measure individual differences in awareness of odours in the environment; the State subscale of the State–Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1968). STAI State was performed on the computer both before and after the moral decision-making task, and a differential score STAI State post–pre was created and introduced in the analyses.

Table 1. Summary Table of Demographic Characteristics and Questionnaires of Study 1a and 1b.

	Study 1a		Study 1b	
	Mean (*SD*)	Range	Mean (*SD*)	Range
No.	17		15	
Gender	9 females	–	11 females	–
Age	23.23 (3.25)	18–32	23.13 (1.62)	20–26
Education	16.18 (1.28)	11–18	16.47 (1.55)	13–18
Threshold test	12.53 (1.69)	8.5–15.5	7.90 (0.90)	6–9.25
Identification test	12.23 (1.52)	10–14	12.87 (1.26)	10–15
BVAQ	42.59 (7.04)	28–53	42.13 (5.09)	34–49
DS	16.17 (5.43)	7.5–25	16.03 (3.38)	10–21.5
STICSA (Trait)	34.18 (6.64)	25–49	36.71 (7.40)	24–50
AQ	17.94 (5.37)	10–30	18.50 (4.45)	11–27
OAS	122.82 (12.75)	101–142	117.07 (17.29)	80–138
STAI (State – PRE)	40.18 (4.36)	27–45	34.33 (7.58)	21–51
STAI (State – POST)	41.00 (4.73)	33–47	36.20 (5.49)	27–47

Note. BVAQ = Bermond–Vorst Alexithymia Questionnaire; DS = Disgust Scale; STICSA = State Trait Inventory for Cognitive and Somatic Anxiety; AQ = Autism-Spectrum Quotient; OAS = Odour Awareness Scale; STAI (State) = State–Trait Anxiety Inventory; POMS = Profile of Mood States.

Odour stimuli. Three odour conditions were used in the task of both studies: no odour, sub-threshold neutral odour and supra-threshold neutral odour (Cedarwood oil; Sigma-Aldrich, Italy). This odour was selected on the basis of on a pilot Study ($N = 53$) showing that its 100% concentration was perceived as a neutral odour (valence rating, $M = 5.0$; $SD = 2.76$ on a scale ranging from 1 to 10). Detection thresholds were determined using a two-alternative forced-choice ascending staircase paradigm with seven reversals and no feedback (Doty, 1991; Lundström, Boyle, & Jones-Gotman, 2008; Lundström, McClintock, & Olsson, 2006). Each trial included one target (a bottle with the diluted odour) and one control stimulus (a bottle with the diluent only). The odour was presented in ascending concentrations until the participant discerned correctly the odour in two successive trials, which triggered a reversal. Mineral oil (Sigma-Aldrich, Italy) was used as diluting agent to create all the concentrations of the odour threshold test necessary to determine the sub- and supra-threshold stimulus for each participant. The dilution series was prepared starting from 100% volume to volume (v/v) in liquid phase of cedarwood oil. From there, the odour was diluted in 16 consecutive dilution steps using a 0.5 volume dilution series (end concentration 0.00305% v/v). Two series of the same odour were prepared and used to allow the odour to saturate the headspace between potential repetitions of the same dilution step. Each dilution step and the matched diluent only were delivered using amber 2-oz glass bottles, all visually identical and containing 10 mL of liquid each. Detection threshold was defined as the geometric mean of the last four reversals. One step below and above the detection threshold was considered as odour concentrations for sub- and supra-threshold conditions, respectively.

Moral dilemmas. Visual stimuli for both studies were 48 moral dilemmas, selected from the 4CONFiDe moral set (Cecchetto et al., submitted). Dilemmas have been revised following the guidelines proposed by Christensen, Flexas, Calabrese, Gut, & Gomila (2014) and Lotto, Manfrinati, and Sarlo (2014; e.g., word count, type of moral transgression, the decision maker's perspective and the type of question). Each dilemma is characterized by four conceptual factors: (a) Personal force: defines whether the agent is directly (personal) or indirectly (impersonal) involved in the production of the harm; (b) Intentionality: defines whether the harm is produced as a non-desired side effect of the action (accidental), or it is used as means to save the others (instrumental); (c) Benefit recipient: defines whether the harm involves the respondent (self-beneficial) or not (other-beneficial); and (d) Evitability: defines whether the harm could be avoided (avoidable) or not (inevitable). Each dilemma was presented on two subsequent screens. The first screen described the scenario, in which a danger threatens to kill a group of people (for instance, "You are an engineer on the international space station ISS. A fire breaks out in the cargo bay. The automatic fire safety system would open the outer door of the cargo bay, letting the oxygen out and putting out the fire. It only works when the inner portal is sealed, but one mechanic is still in the cargo bay. He doesn't have the time to take off the bulky space suit, which will get him stuck in the inner portal, causing the fire to spread and to kill you all."), plus a hypothetical action that would save these people but harm others ("If you manually close the portal the emergency system will be activated and it will put out the fire. This will suck the mechanic into space and you kill him, but you will save yourself and the other ten astronauts."). The second screen presented the question ("Do you put out the fire by manually sealing the inner portal, which will suck the mechanic into space, so the fire won't reach you and the ten astronauts?"). Participants had to choose between two options: "I do it," and "I do not do it." The first choice is considered to be utilitarian, as it maximises overall utility (i.e., saving more lives), whereas the second choice was considered deontological. Moral dilemmas were designed in such a way that the affirmative choice was always the utilitarian option (as in Christensen et al., 2014). The moral tendency of each participant is based on the relative frequency of these reciprocal choices. Dilemmas were presented using black font color (font: Calibri, size: 24) against a white background on a 19-in. computer screen at a viewing distance of 60 cm. Stimulus presentation was delivered with E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

Procedure. Upon arrival, each participant was seated in a quiet room and asked to complete the self-report questionnaires, the odour identification test (Hummel et al., 1997) and the odour detection threshold test. Afterwards, participants were asked to seat in front of a computer screen and they performed a practice session (two moral dilemmas) and then the moral decision-making task. Participants were instructed using an Italian version of the instructions suggested by Christensen et al. (2014): "In the following test you will read a series of short stories about difficult interpersonal situations, similar to those that you could see on the news every day or may watch in a movie. For each of the difficult situations a solution will be proposed. You have to decide whether or not you would act as suggested. Do not linger too much in thinking but try to identify yourself with the characters of the stories." Each trial began with a white screen presented for 4 s followed by a black and green crosses displayed respectively for 6 s (jittered) and 0.5 s. Successively, the scenario was presented, displayed until the participants' click of the mouse, followed by a white screen during which the odour was released for 3 s. Odours were presented birhinally using a computer-automated olfactometer delivering odours in a temporally precise, square-shaped manner (Lundström et al., 2010). A low birhinal flow rate of 3.0 L/m (a total of 1.5 L/m per nostril) for a total duration of 3 s per stimulus was used to prevent irritation of the nasal mucosa over time (Lötsch, Ahne, Kunder, Kobal, & Hummel, 1998; Lundström et al., 2010). After each odour presentation, clean air was presented to minimize odour residuals (Parma, Ferraro, Miller, Åhs, & Lundström, 2015; Seubert, Gregory, Chamberland, Dessirier, & Lundström, 2014), while the question slide was presented. The two choice options were displayed below the question. Participants were instructed to make their choice as fast as possible but there was no time restriction. Following every answer, two rating slides were presented. Participants rated how arousing and pleasant the odour was on a 10-cm Visual Analog Scale (VAS). Higher scores indicate greater arousal and pleasantness. Participants were instructed to answer even if they did not perceive any odour within a 6-s time window/rating. Dilemmas were presented in three blocks of 16 trials (a total of 48 trials/subject), in which odours were presented in an event-related manner. Participants were allowed to take a short break at the end of each block. At the end of the moral decision-making task, participants completed the second version of the STAI State.

Statistical analysis. Data were analyzed with linear mixed-effects models (LMMs) using R (version 2.10.1; http://www.r-project.org/) and in particular using *lme* function (*nlme* package; https://cran.r-project.org/web/packages/nlme/nlme.pdf) for continuous variables and the *glmer* function (*lme4* package; http://cran.r-project.org/web/packages/lme4/index.html) for the binary variable. To account for individual differences (e.g., some people are more "deontological" than others), participants were included in the models as *random*. To avoid a warning of non-convergence, an optimizer (bobyqa) was applied (Powell, 2009). Results with and without the optimizer are not significantly different (https://github.com/lme4/lme4/blob/master/misc/notes/release_notes.md). Estimates on the choice between utilitarian and deontological responses were based on an adaptive Gaussian Hermite approximation of the likelihood with 10 integration points. All models included odour factor, as the main interest of our analysis, and the four conceptual moral factors (*Personal force*, *Intentionality*, *Benefit recipient* and *Evitability*) as factors describing our items. Moreover, for each dependent variable, at the beginning, all self-report questionnaires, relative to our participants traits, and second-level interactions as fixed effects was built, were included (Crepaldi et al., 2012; Faraway, 2005; McLean, Sanders, & Stroup, 1991; Wehling et al., 2016) and then they were progressively removed stepwise until the deletion of any additional effect caused a significant loss of fit to the model (as tested by the Akaike Information Criterion (AIC) tests resulting from the use of the generic *anova* function). Reduced AIC was used as criterion for model selection because it favours parsimonious models, also when the sample size is small (Bolker et al., 2009).

Finally, to test whether the odour condition significantly increases the explained variance of the final model selected, such model was directly contrasted with the same model without the odor term, included as a main effect or in interaction with the dilemma features. The two models were compared using the general *anova* function: In the results section, X^2 and p value are stated for moral choice analysis while L. Ratio and p value are reported for continuous dependent variables (SCR and IHR). Additionally, description of the selected model and the AIC value per model were reported.

Outliers with respect of reading times and reaction times were removed considering the outlier-labelling rule (Hoaglin, Iglewicz, & Tukey, 1986). From a starting number of 816 trials, 19 trials were removed because of extremes reading times ($>$49.27 s; $N = 19/816$, 2.32%) while 33 trials were removed because of extremely long choice reaction times ($>$9.25 s; $N = 33/797$, 4.14%). Final analyses were run on a sample of 764 trials distributed over conditions.

Results

Sub- and supra-threshold odour conditions do not differ in arousal ratings. The LMM on arousal ratings (no-odour: $M = 7.22$, $SD = 0.07$; sub-threshold neutral odour: $M = 7.08$, $SD = 0.07$;

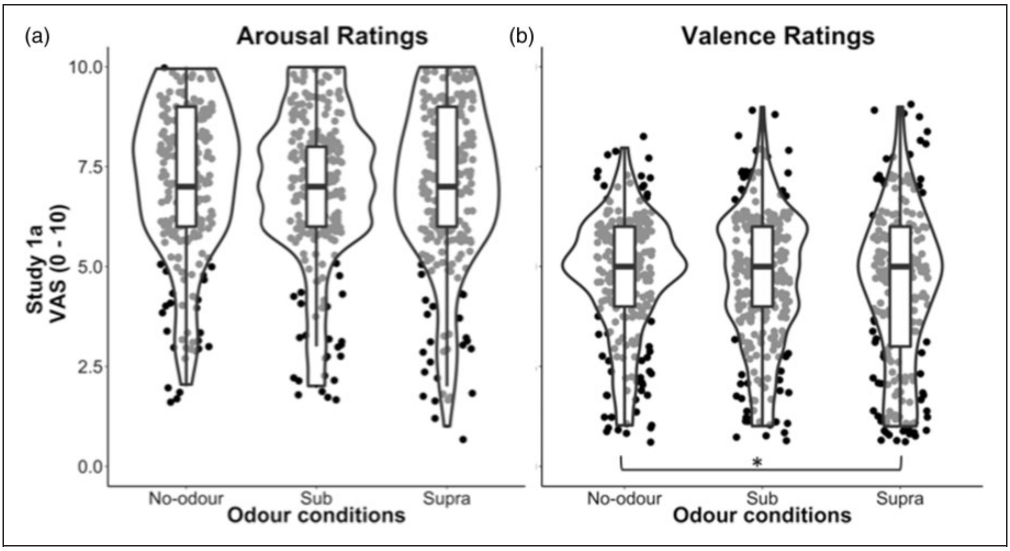

Figure 1. (a) Distribution of participants' arousal odour ratings of Study 1a. (b) Distribution of participants' valence ratings of Study 1a. The black dots represent the value of each participant's rating, per odour condition, whereas the box-plot represents the interquartile range of each distribution, with the thick black horizontal bar corresponding to the median. Each box-plot is surrounded by a violin plot representing the smoothed distribution of data.

and supra-threshold neutral odour: $M = 7.02$, $SD = 0.07$; Figure 1(a)) showed no significant differences across odour conditions (all $t < 1.3$, all $p > .2$). Please refer to Table 1SI of Supplemental materials for descriptive data.

The LMM on valence ratings (no-odour: $M = 4.76$, $SD = 0.06$; sub-threshold neutral odour: $M = 4.68$, $SD = 0.06$; and supra-threshold neutral odour: $M = 4.45$, $SD = 0.07$) revealed no significant difference between sub- and supra-threshold odour condition and between sub-threshold and no-odour conditions (all $t < 0.7$, all $p > .1$; Figure 1(b)). Considering no-odour condition as reference the model showed a significant difference between supra-threshold and no-odour conditions [$t(745) = -2.22$, $p = .03$].

Both sub- and supra-threshold neutral odour increase deontological choices. The best fitting model for moral choice data (reference factor: utilitarian choice; AIC = 884.79; $X^2 = 30.73$, $p < .001$) was the one including the odour condition ($p < .001$), personal force ($p < .001$), intentionality ($p < .001$), benefit recipient ($p = .04$) and evitability ($p = .38$), the interaction of odour and each of these three factors, and the scores at AQ ($p = .001$), DS ($p = .001$) and STAI ($p = .03$; see Table 2 for descriptive data of single parameters). No effect of single odour conditions on moral choice was retrieved (all $z < 0.3$, all $p > .2$). However, odour significantly interacted with the dilemma factor personal force (reference factors: sub-threshold odour and personal). Post hoc tests (*lsmeans* function) revealed a selective effect of odour on impersonal dilemmas. Specifically, the supra-threshold odour condition, as compared to the no-odour condition, significantly increased the number of deontological choices to impersonal dilemmas ($p = .02$). The sub-threshold odour showed a significant effect in the same direction (sub-threshold vs. no odour, $p = .04$). However, no other contrasts reached the significance level. Additionally, odour significantly interacted with the dilemma factor intentionality (reference factors: sub-threshold odour and accidental). Post hoc tests (*lsmeans* function) showed a selective increase

Table 2. Summary of the Best Linear Mixed Effects Model on Moral Choices for Study 1a.

Moral choices						95% *CI*	
Fixed effects	β	*SE*	*z* value	*p* value	β exp	Lower	Upper
Intercept	0.01	0.81	0.02	0.987	1.013	0.206	4.971
No-odour	0.10	0.52	0.19	0.852	1.101	0.401	3.022
Supra-threshold neutral odour	−0.34	0.58	−0.58	0.563	0.713	0.227	2.243
Personal force (*Impersonal*)	−0.81	0.32	−2.52	**0.012**	0.447	0.239	0.835
Intentionality (*Instrumental*)	1.20	0.33	3.58	<**0.001**	3.316	1.721	6.392
Benefit recipient (*Self*)	−0.83	0.31	−2.65	**0.008**	0.437	0.237	0.806
Evitability (*Inevitable)*	−0.35	0.33	−1.08	0.281	0.704	0.372	1.333
AQ	−0.15	0.04	−3.69	<**0.001**	0.859	0.792	0.931
DS	0.17	0.04	3.73	<**0.001**	1.182	1.082	1.290
STAI trait difference	0.06	0.03	2.24	**0.025**	1.063	1.008	1.121
No-odour × Personal Force (*Impersonal*)	−1.57	0.60	−2.63	**0.009**	0.209	0.065	0.672
Supra-odour × Personal Force (*Impersonal*)	0.23	0.44	0.52	0.603	1.260	0.527	3.011
No-odour × Intentionality (*Instrumental*)	−1.19	0.49	−2.44	**0.015**	0.305	0.118	0.791
Supra-odour × Intentionality (*Instrumental*)	−0.43	0.45	−0.95	0.343	0.652	0.269	1.578
No-odour × Benefit Recipient (*Self*)	0.75	0.43	1.72	0.085	2.111	0.902	4.944
Supra-odour × Benefit Recipient (*Self*)	1.17	0.52	2.25	**0.024**	3.224	1.164	8.927
No-odour × Evitability (*Inevitable*)	0.38	0.45	0.84	0.399	1.457	0.607	3.498
Supra-odour × Evitability (*Inevitable*)	−0.28	0.57	−0.50	0.619	0.752	0.246	2.305

Note. β = estimate; *SE* = standard error; *CI* = confidence interval; β exp = exponential of β coefficient; Sub-threshold odour = sub-threshold neutral odour condition; Supra-threshold odour = supra-threshold neutral odour condition; DS = disgust scale; STAI = State subscale of the State–Trait Anxiety Inventory; AQ = Autism-Spectrum Quotient. Significant *p* values are reported in bold. Table shows model with utilitarian choice and sub-threshold odour condition set as references. Contrast condition from the reference for categorical factors is reported in italic inside bracket.

of deontological responses on instrumental dilemmas following the exposure to the supra-threshold odour (vs. no-odour, $p = .01$) and following sub-threshold odour (vs. no-odour, $p = .001$). Finally, the factor odour interacts with the benefit recipient factor (reference factors: sub-threshold odour and other). Post hoc tests (*lsmeans* function) showed a selective increase of deontological responses on other-recipient dilemmas following the exposure to the sub-threshold odour (vs. no-odour, $p = .04$). Irrespective of the odour, the likelihood of choosing the deontological option increased when dilemmas were personal (vs. impersonal), instrumental (harm was intentional vs. accidental) and other-benefit (vs. self-benefit), with reduced autistic traits (i.e., lower AQ scores), increased anxiety (i.e., greater STAI scores) and increased disgust sensitivity (i.e., greater DS scores).

Discussion

Study 1a was designed to investigate whether moral decision-making is biased by different intensities of an emotionally neutral olfactory stimulus, either supra-threshold or sub-threshold intensities. Subjective ratings of arousal and valence did not reveal any difference between sub- and supra-threshold odour conditions but only between no-odour and supra-odour conditions for valence ratings. The homogeneity in the arousal ratings might indicate that sub- and supra-threshold odour conditions were not sufficiently different at the perceptual level. This might explain the lack of main effect of odour on deontological response rate. These data seem to support our first hypothesis, stating that odour intensity does not critically modulate moral choice, perhaps because neutral odours are not inducing a disgust reaction in the decision maker. If this were completely true, no odour effect on moral choice should be present. However, results of Study 1a reveal three odour-dilemma factor interactions. First, both supra-threshold and sub-threshold odour conditions increase the choice of deontological responses, but such effect is confined to impersonal and instrumental dilemmas. Second, the sub-threshold odour increases deontological responses only for dilemmas in which others benefit from the moral choice. Altogether these data suggest that the odour – irrespective of its intensity – increases deontological responses to the dilemmas perceived as less arousing (Christensen et al., 2014; Lotto et al., 2014; Moore, Clark, & Kane, 2008).

In line with previous literature, participants provided more deontological responses when the moral dilemma was personal (Christensen et al., 2014; Greene et al., 2004; Greene et al., 2009; Greene et al., 2008; Koenigs et al., 2007; Mendez, Anderson, & Shapira, 2005; Moore et al., 2008; Moore, Lee, Clark, & Conway, 2011; Moretto et al., 2009), instrumental (Borg, Hynes, Van Horn, Grafton, & Sinnott-Armstrong, 2006; Christensen et al., 2014; Cushman, Young, & Hauser, 2006; Greene et al., 2009; Hauser, Cushman, Young, Kang-Xing Jin, & Mikhail, 2007; Lotto et al., 2014; Moore et al., 2008; Sarlo et al., 2012) and/or self-beneficent (Christensen et al., 2014; Lotto et al., 2014; Moore et al., 2008).

Moreover, according to the literature, we confirmed that the deontological moral tendency is reduced in individuals reporting autistic traits (Buon et al., 2013; Moran et al., 2011; but see Patil, Melsbach, Hennig-Fast, & Silani, 2016), higher anxiety (Starcke et al., 2008; Youssef et al., 2012a) and increased in those exhibiting higher disgust sensitivity (Choe & Min, 2011; Schnall et al., 2008; Ugazio et al., 2012, but see Ong, O'Dhaniel, Kwok, & Lim, 2014).

In light of the lack of significant effects between sub- and supra-threshold arousal ratings, in the next study we will assess the hypotheses tested here in an independent sample of participants, incrementing the concentration difference between sub- and supra-threshold odour conditions. Furthermore, we will extend the evaluation of odour-induced arousal and valence effects to physiological reactions, known implicit indicators of emotional experiences (e.g., Lang, 1995).

Study 1b – Does Odour Intensity Affect the Psychophysiological Correlates of Moral Choice?

Material and Methods

Participants. Fifteen participants were included in Study 1b. All screening procedures were the same as Study 1a. See Table 1 for participants' characteristics.

Stimuli. The same moral dilemmas, odour conditions, as well as the procedure for establishing odour concentrations used in Study 1a were used in Study 1b. As to avoid the distribution of odour thresholds across participants being skewed towards one end of the intensity scale, the average threshold found for Study 1a was centred on the dilution series scale. In this way, the dilution series in Study 1b was prepared using 12.5% v/v as dilution starting point. From there, the odour was diluted in 16 consecutive dilution steps using a 0.5-volume dilution series (end concentration 0.00038% v/v). To increase the perceptual distance between odour conditions, two steps below and two above the detection threshold of each participant were considered as odour concentrations for sub- and supra-threshold conditions, respectively.

Procedure. The procedure and task was the same as in Study 1a except for the following improvements. SCR electrodes and the photoplethysmographic probe to measure cardiac activity were attached ~10 min before the beginning of the tasks and ~1 min of baseline was recorded at the beginning of first block. To avoid fatigue effects due to a long experimental session, we presented the odour ratings at the beginning and at the end of the moral decision-making task. Each odour presentation was preceded by a green fixation cross on the screen for 0.5 s followed by a black screen while an odour was presented for 4 s; a white screen followed for an average interstimulus interval of 6 s (±0.12 s). Subsequently, two questions were asked in random order, namely "How intense was the odour you just smelled?" and "How pleasant was the odour you just smelled?" Perceptual ratings for odour intensity and pleasantness were collected on a 10-cm computerized VAS, ranging from "not at all" to "very much." Participants were instructed to answer even if they did not perceive odour. In the moral decision-making task, the scenario was presented for a fixed time (10 s) plus the time needed by participants to complete reading the slide. Moral decisions were timed to a maximum of 6 s.

Psychophysiological data acquisition and analysis. SCR and HR were recorded with a *PROCOMP infiniti system* (Thought Technology, Montreal, Canada). SCR was recorded using a pair of prewired 8 mm Ag/AgCl electrodes, attached to the surface of the medial phalanx of the index and ring fingers of the non-dominant hand as suggested on the *PROCOMP infiniti system* manual. Conductive gel was used to reduce impedance. The electrode pair was excited with a constant voltage of 0.5 V and conductance was recorded using a DC amplifier with a low-pass filter set at 64 Hz. Such procedures are in accordance with the guidelines by Figner and Murphy (2011) and Boucsein (2012). A photoplethysmographic probe (3.2 cm/1.8 cm, photodetector LED type), placed on the middle finger of the non-dominant hand was used to assess HR in beats per minute (bpm) at a sample rate of 2048 Hz. SCR and HR data were analysed with Matlab using the same in-house scripts used in our previous study (Cecchetto, Korb, Rumiati, & Aiello, under review), and partially using the EEGLAB toolbox (http://sccn.ucsd.edu/eeglab/).

SCR data were filtered with 10 Hz low-pass filters and epoched over the 21 s from the odour presentation. Two seconds before each odour presentation served as baseline. *Peak amplitude* was analysed, defined as the difference in μSiemens between the mean value during baseline and the peak after stimulus onset. Trials with peak amplitudes below 0.01 μSiemens were excluded from the analysis. To improve interpretability, peak amplitudes were log-transformed (Boucsein, 2012).

Heart rate data were filtered with 1 Hz high-pass filter and resampled to 256 Hz. Beat detection was performed automatically, verified visually and corrected, if necessary. Frequency was computed as beats per minute (bpm). The 9 s from the odour presentation were divided in six time windows of 1.5 s. Interbeat intervals were computed, transformed to heart rate values and averaged for each 1.5 s window. Each time windows was then corrected by subtracting the 1.5 s before odour presentations to obtain the IHR (Palomba et al., 2000). Relatively to the trial design, the odour was presented during Time Window 1 and 2, the question slide appeared at the beginning of the third time window and the amount of time available to the participants to the answer ended at the end of the sixth time window.

Statistical analysis. For the behavioural and IHR analyses, no reaction times (RT) choice outliers were identified (720 trials). For the SCR analyses, a subset of data was included. Specifically, data from one subject were removed due to technical issues. Of the remaining 672 trials, 139 were removed due to SCR peak amplitude lower than 0.01 μSiemens (Roth et al., 2012; $N = 139/672$, 20.7%, mostly due to habituation issues towards the end of the last two blocks, Boucsein, 2012, pp. 275–282). Final analyses were run on a sample of 533 trials distributed over conditions. For all other aspects, analyses are equivalent to those presented for Study 1a. Please refer to Study 1a statistical analysis section for details.

Results

The supra-threshold odour is more intense– but not more pleasant – than the sub-threshold odour. We tested whether the three odour conditions had the expected perceptual impact. Since there were no significant differences between the ratings before and after the moral decision-making task, data from the two sessions were collapsed. As evident from Figure 2(a), a LMM on odour intensity ratings (no-odour: $M = 2.70$, $SD = 0.21$; sub-threshold neutral odour: $M = 3.97$, $SD = 0.25$; and supra-threshold neutral odour: $M = 6.97$, $SD = 0.20$) revealed a significant difference between odour conditions: The supra-threshold odour condition was perceived as significantly more intense than both no-odour ($p < .0001$; the reference factor was set in no-odour) and sub-threshold odour conditions ($p < .0001$; the reference factor was sub-threshold odour); moreover, the sub-threshold odour showed a significance difference compared to no-odour condition ($p = .02$).

For valence ratings (no-odour: $M = 4.31$, $SD = 1.93$; sub-threshold neutral odour: $M = 4.03$, $SD = 2.35$; supra-threshold neutral odour: $M = 3.60$, $SD = 1.89$), no significant differences were found (all $t < 0.6$, all $p > .5$; Figure 2(b)). For the full LMM results, please refer to Table 2SI of the Supplemental materials.

Deontological choice rate increases during the sub- threshold odour condition. The best fitting model for moral choice data (reference factor: utilitarian choice; AIC = 884.88; $X^2 = 38.06$, $p < .001$) resulted being the one including the odour condition ($p < .001$), personal force ($p = .001$), intentionality ($p < .001$), benefit recipient ($p = .01$) and evitability ($p = .004$), the interaction of odour and each of these three factors, and the scores at AQ ($p = .03$; see Table 3 for descriptive data of single parameters). Four main effects were found to modulate the moral choice tendency: the odour condition, the personal force factor, the evitability factor and AQ (reference factors: sub-threshold odour and personal). The likelihood of choosing deontological responses significantly increased following the exposure to the sub-threshold odour as compared to the supra-threshold odour condition. Changing no-odour condition as reference factor reveals an increment of deontological responses following the exposure to the sub-threshold odour when compared to the no-odour condition, $z(720) = 2.26$, $p = .02$. Although the model produced three significant interactions (Odour × Intentionality, Odour × Benefit Recipient and Odour × Evitability; reference factors: sub-threshold odour, accidental, other, avoidable), the post hoc contrasts (*lsmeans* function) reveal meaningful significant contrasts only for the interaction Odour × Evitability: a selective increase of deontological responses on avoidable dilemmas following the exposure to the sub-threshold odour compared to no-odour ($p = .02$) and compared to supra-threshold odour conditions ($p = .03$). Moreover, as found in Study 1a, the likelihood of choosing deontological responses increased when the dilemmas were personal (vs. impersonal), when avoidable (vs. inevitable) and with lower AQ scores.

SCR is greater for sub- and supra-threshold odour conditions compared to clean air. The best fitting model for amplitude profiles of SCR (AIC = −312.89; L. Ratio = 26.82; $p < .001$) was the one including the odour factor ($p < .001$), moral choice ($p = .09$) and the interaction between the two factors, personal force ($p = .06$), intentionality ($p = .007$), benefit recipient ($p = .09$) and

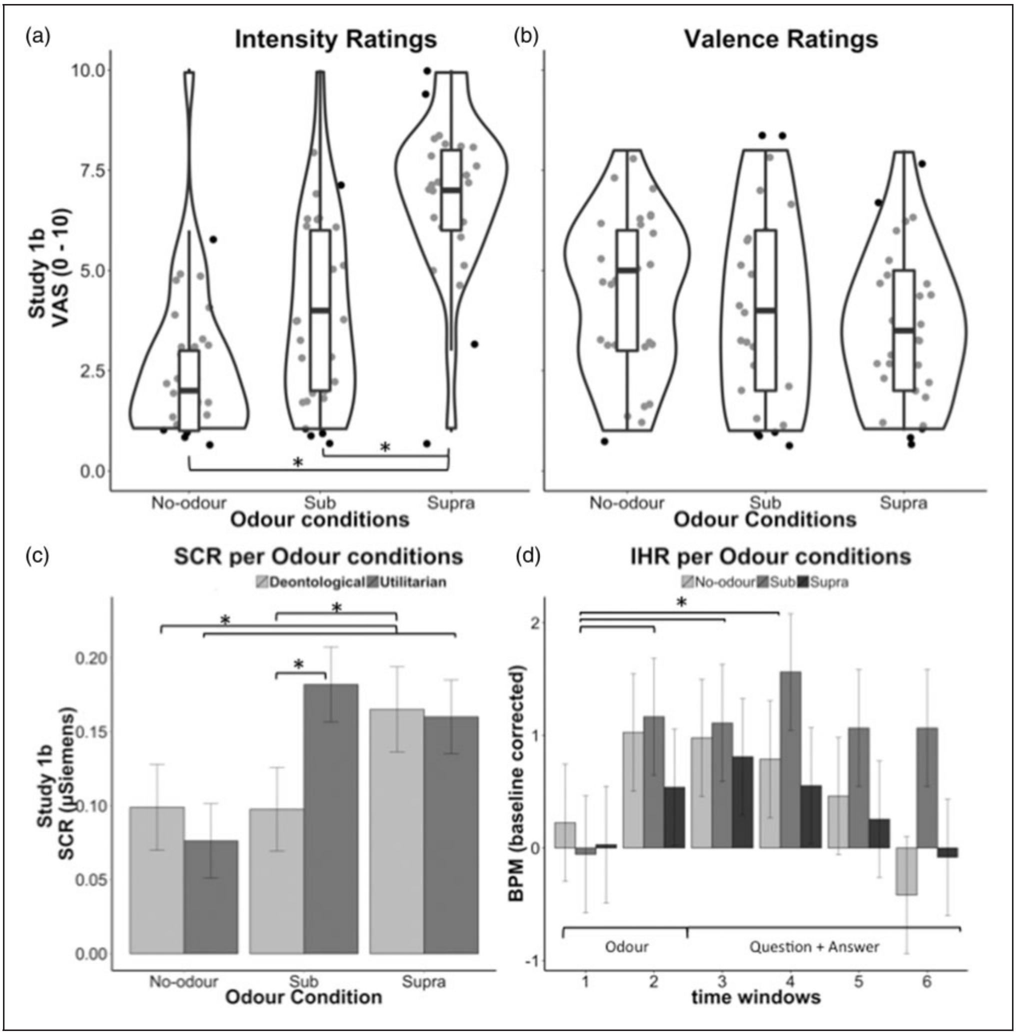

Figure 2. (a) Distribution of participants' intensity odour ratings of Study 1b. (b) Distribution of participants' valence ratings of Study 1b. (c) SCR per odour conditions of Study 1b. (d) IHR per time window and odour conditions of Study 1b. ((a) and b)) The black dots represent single data points, whereas the box-plot represents the interquartile range of each distribution, with the thick black horizontal bar corresponding to the median. Each box-plot is surrounded by a violin plot representing the smoothed distribution of data. Significant differences are indicated.

evitability ($p = .34$) and the scores at AQ ($p = .04$; see Table 3SI of Supplemental materials for descriptive data of single parameters). The likelihood of presenting greater SCR increases during supra-threshold odour conditions compared to sub-threshold odour condition ($p = .03$) and to no-odour condition ($p = .03$), but no significant difference is evident in SCR between sub-threshold and no-odour conditions ($p = .97$). Moreover, the SCR amplitude significantly increases for utilitarian choice compared to deontological choice. The odour significantly interacts with the moral choice (reference factors: sub-threshold odour conditions and utilitarian choices): Post hoc analysis (*lsmeans* function) indicates

Table 3. Summary of the Best Linear Mixed Effects Model on Moral Choices for Study 1b.

Moral choices						95% CI	
Fixed effects with reference to sub-threshold odour	β	*SE*	*z* value	*p* value	β exp	Lower	Upper
Intercept	2.20	0.88	2.50	**0.012**	9.012	1.610	50.440
No-odour	−1.17	0.52	−2.26	**0.024**	0.310	0.112	0.857
Supra-threshold neutral odour	−1.74	0.54	−3.25	**0.001**	0.175	0.061	0.500
Personal force (*Impersonal*)	−1.13	0.31	−3.60	<**0.001**	0.324	0.176	0.598
Intentionality (*Instrumental*)	0.32	0.34	0.95	0.343	1.378	0.710	2.675
Benefit recipient (*Self*)	−0.12	0.36	−0.33	0.739	0.886	0.434	1.808
Evitability (*Inevitable*)	−0.90	0.31	−2.87	**0.004**	0.406	0.219	0.752
AQ	−0.10	0.04	−2.30	**0.022**	0.907	0.834	0.986
No-odour × Personal Force (*Impersonal*)	0.80	0.54	1.49	0.136	2.235	0.777	6.430
Supra-odour × Personal Force (*Impersonal*)	0.63	0.46	1.37	0.169	1.877	0.765	4.607
No-odour × Intentionality (*Instrumental*)	0.99	0.48	2.03	**0.042**	2.679	1.036	6.928
Supra-odour × Intentionality (*Instrumental*)	0.75	0.47	1.59	0.112	2.120	0.840	5.347
No-odour × Benefit Recipient (*Self*)	−1.46	0.64	−2.30	**0.022**	0.231	0.066	0.807
Supra-odour × Benefit Recipient (*Self*)	0.18	0.51	0.36	0.719	1.200	0.445	3.234
No-odour × Evitability (*Inevitable*)	1.56	0.47	3.32	**0.001**	4.760	1.897	11.944
Supra-odour × Evitability (*Inevitable*)	1.22	0.45	2.72	**0.006**	3.392	1.408	8.172

Note. β = estimate; SE = standard error; β exp = exponential of β coefficient; 95% CI = confidence interval; sub-threshold odour = sub-threshold neutral odour condition; supra-threshold odour = supra-threshold neutral odour condition; AQ = Autism-Spectrum Quotient. Significant p values are reported in bold. Table shows model with utilitarian choice and sub-threshold odour condition set as references. Contrast condition from the reference for categorical factors is reported in italic inside bracket.

that in utilitarian choices greater SCR is associated to both odour conditions (sub: $p < .001$; supra: $p = .007$), irrespective of their intensity (Figure 2(c)). Although no significant differences in post hoc contrasts were revealed for deontological choices, greater SCR is nominally associated with supra-threshold, but not with sub-threshold and no-odour conditions. Moreover, the likelihood of showing a greater SCR increases when the dilemmas presented were accidental. Moreover, the likelihood of presenting greater SCR increases with higher AQ scores.

IHR decelerates during sub- and supra-threshold odour condition. The best model explaining IHR activity included (AIC = 27876.54; L. Ratio = 10.64, $p = .005$), time ($p = .02$), odour conditions ($p = .004$), personal force ($p = .93$), intentionality ($p = .66$), benefit recipient ($p = .08$), evitability ($p = .67$), moral choice ($p = .21$) and the scores at STAI ($p = .04$; see Table 4SI of Supplemental materials for descriptive data of single parameters). The likelihood of presenting an decelerated IHR is affected by the odour smelled. In detail, a significant IHR deceleration is evident when participants smell the sub- and supra-threshold odour conditions compared to no-odour ($p = .004$ and $p = .005$, respectively), but no differences emerge between sub- and supra-threshold odour conditions ($p = .91$). Also, a time effect is present: IHR significantly accelerates compared to odour onset (Time Window 1) during the second half of the odour stimulation (irrespective of the odour valence), during the presentation of the question slide (Time Windows 2 to 4; Figure 2(d)). Finally, there is an effect of anxiety: The greater the STAI score (i.e., the more anxious the participant), the greater the IHR deceleration.

Discussion

The goal of Study 1b was to re-evaluate the hypotheses on the effects of odour intensity on moral choice tested in Study 1a, by using odour conditions that were more perceptually discriminable between each other. As the analysis of the odour intensity ratings reveals, in Study 1b the three odour conditions are parametrically distributed: The supra-threshold odour condition was significantly more intense than the sub-threshold odour condition, which itself was significantly more intense than the no-odour condition. Furthermore, the odour valence ratings resulted homogenous across conditions, indicating that the olfactory effects on moral choice at the behavioural and psychophysiological level can be attributed to odour intensity alone.

Deontological choices are more likely to be made in the presence of a sub-threshold odour as compared to the supra-threshold odour and no odour. This pattern of results supports the hypothesis that the neutral odour condition impacts on moral choice only when it is presented sub-threshold. We suggest that this effect might emerge because the elaboration of irrelevant sensory information – whose sensory signal is minimal – can escape strategic inhibitory control (e.g., Li, Moallem, Paller, & Gottfried, 2007). As previously shown, odours – even when presented in very low concentration – can constitute a distractor for the process of acting, whether acting is considered as a real movement (i.e., Parma, Bulgheroni, Scaravilli, Tirindelli, & Castiello, 2013; Parma et al., 2012) or, as in the present case, whether acting is considered as a decision to act. In other words, during moral decision-making task, the information irrelevant to the decision is processed unconsciously and it biases the moral choice towards a more emotional tendency, given that cognitive resources have been taxed by the presence of the irrelevant stimulus (Greene et al., 2008).

One may think that the results of Study 1b are in contrast to the results of Study 1a. However, we confirm the effects on moral choice that are not dependent on odour variables, revealing a consistent increase in deontological responses for personal dilemmas as well as the tendency of participants reporting higher autistic traits to prefer utilitarian choices. With respect to the odour variables, a clearer definition of the relative intensity of the odour conditions allowed to show that a disgust reaction is not the only factor able to modulate moral choices.

The psychophysiological analyses confirm that the behavioural findings are strictly dependent on differences in intensity of the odours. Indeed, arousal measured through SCR reveals that arousal is increased following the exposure to the supra-threshold odour condition with respect to the sub-threshold odour condition. This is in line with the idea that increments in SCR correspond to the orientation towards newly introduced stimuli (e.g., Frith & Allen, 1983). Furthermore, the analysis of SCR is consistent with the differences in odour intensity reported subjectively. Interestingly, this effect is conserved when considering deontological choices, whereas SCR does not track odour intensity in utilitarian choices. Considering that the literature reports that utilitarian choices are associated with greater SCR as compared to deontological choices (Moretto et al., 2009), the odour effect is hidden by the ceiling effect of arousal in utilitarian choice. In other words, the arousal induced by the processing of the utilitarian choice is already high enough not to leave room for the influence of the odour.

To strengthen the idea that in Study 1b the effect of odour pleasantness was minimal, in line with the homogeneity of pleasantness ratings, the analysis of IHR showed no significant differences across sub- and supra-threshold conditions. This is in line with previous evidence showing that cardiac responses vary with hedonic values and reports of pleasantness (Alaoui-Ismaïli, Robin, Rada, Dittmar, & Vernet-Maury, 1997; Alaoui-Ismaili, Vernet-Maury, Dittmar, Delhomme, & Chanel, 1997; Bensafi et al., 2002). The reduction of the cardiac output emerging in the presence of both odour conditions as compared to the no-odour condition is to be attributed to the attentional processing of the stimuli (Bradley, 2009).

Here, we extend for the first time the study moral behavioural and psychophysiological effects to the odour intensity of an emotionally neutral stimulus, suggesting that odour intensity impacts on moral decision-making, by promoting a deontological moral tendency, as confirmed by the psychophysiological findings. However, the effect of odour valence on moral decision-making has still to cover the full spectrum of possibilities, ranging from unpleasant to pleasant odours. In Study 2, we address this issue by considering the effect of a neutral, pleasant and unpleasant sub-threshold odours in moral decision-making.

Study 2 – Does Odour Valence Affect the Behavioural and Psychophysiological Correlates of Moral Choice?

Material and Methods

Participants. A total of naïve 15 participants (Table 4), following the screening procedures of Study 1a and 1b, were included in Study 2.

Odour stimuli. In Study 2, three odour conditions were presented during the moral decision making task: no-odour, neutral sub-threshold odour condition (cedarwood oil, Sigma-Aldrich, Italy) and a solution of butyric acid presented in sub-threshold concentration (Sigma-Aldrich, Italy). Butyric acid was chosen in virtue of its hedonic ambiguity. Indeed, it has been reported to be perceived either as a pleasant odour (e.g., parmesan cheese) or an unpleasant odour (e.g., vomit; Herz, 2006; Herz & von Clef, 2001), while keeping the chemical properties constant. Mineral oil (Sigma-Aldrich, Italy) was used as diluting agent for cedarwood oil, while propylene glycol (Sigma-Aldrich, Italy) was used for butyric acid. All concentrations below are given as volume to volume (v/v) in liquid phase. Odour

Table 4. Summary Table of Demographic Characteristics and Questionnaires of Study 2.

	Mean (*SD*)	Range
Gender	13 females	–
Age	25.80 (4.95)	19–38
Education	16.93 (2.49)	13–20
Threshold test (*Cedarwood Oil*)	8.75 (1.12)	6.25–12.25
Threshold test (*Butyric Acid*)	12.38 (0.34)	11.5–14.5
Identification test	13.27 (1.33)	11–16
BVAQ	46.07 (5.50)	35–52
DS	15.17 (4.16)	7–24
STICSA (*Trait*)	39.53 (11.09)	23–65
AQ	17.87 (6.01)	8–28
OAS	120.40 (12.29)	103–139
STAI (State – PRE)	35.00 (6.96)	25–52
STAI (State – POST)	37.13 (810.20)	25–59

Note: BVAQ = Bermond–Vorst Alexithymia Questionnaire; DS = Disgust Scale; STICSA = State Trait Inventory for Cognitive and Somatic Anxiety; AQ = Autism-Spectrum Quotient; OAS = Odour Awareness Scale; STAI (State) = State–Trait Anxiety Inventory; POMS = Profile of Mood States.

concentrations for the cedarwood oil and butyric acid odours were established for each participant through the same odour detection threshold test used in Study 1b.

Based on the pre-/post-task average valence rating of each participant, the original group was split in a Pleasant ($N = 8$; rating above median split, pleasantness $> 5/10$) and an Unpleasant group ($N = 7$; rating below median split, $< 5/10$). In case the mean was 5.0, values of ratings at the end of the study were considered (rating above median split, namely $\geq 5/10$, Pleasant group; rating below median split, namely $< 5/10$, Unpleasant group).

Procedure. In Study 2 we replicated the procedure, visual stimuli, psychophysiological acquisition and statistical analyses used in Study 1b. Only the odour conditions, described earlier, have partially changed.

Statistical analysis. Behavioural and IHR analyses were performed on a total of 720 trials: No outliers were identified considering the reaction times. Analyses on SCR data were calculated on a total of 537 trials, due to SCR peak amplitude lower than 0.01 μSiemens (Roth et al., 2012; $N = 183/720$, 25.41%, mostly due to habituation issues towards the end of the last two blocks, Boucsein, 2012, pp. 275–282). Removed trials were distributed over 15 subjects and equally over conditions. The analyses are equivalent to those presented for Study 1a and 1b, except for the addition of Wilcoxon test for the analysis of the ratings across groups.

Results

Odour conditions are perceived as different in intensity and in valence. Given that no significant differences between the answers before and after the moral decision-making task were found, the data from the two sessions were collapsed. The LMM on odour intensity ratings (no-odour: $M = 2.77$, $SD = 0.17$; neutral odour: $M = 3.80$, $SD = 0.22$; pleasant odour: $M = 4.25$, $SD = 0.21$; unpleasant odour: $M = 3.21$, $SD = 0.17$) showed a main effect of odour condition (reference factor no-odour): Pleasant odour condition and neutral odour conditions were rated as more intense than the no-odour condition (respectively: $p = .02$ and $p = .01$; Figure 3(a)). Changing the reference factor does not reveal other significant effects.

Wilcoxon tests on odour valence ratings were performed to evaluate whether no-odour and neutral odour conditions were equivalent across groups. Results showed that no significant differences were evident for no-odour condition (group Pleasant: $M = 4.88$, $SD = 0.07$; group Unpleasant: $M = 4.29$, $SD = 0.33$; $w = 123$, $p = .23$, 95%CI: $[-1.03 \times 10^{-6}, 2.00]$) and for neutral odour condition (group Pleasant: $M = 5.06$, $SD = 0.21$; group Unpleasant: $M = 3.93$, $SD = 0.29$; $w = 156.5$, $p = .06$, 95%CI: $[-3.85 \times 10^{-5}, 2.99]$). As expected, there was a significant difference in the valence attributed to butyric acid across groups (group Pleasant: $M = 5.38$, $SD = 0.14$; group Unpleasant: $M = 3.36$, $SD = 0.31$; $w = 182.5$, $p = .002$, 95%CI: 0.99, 3.00]). A LMM on odour valence ratings showed a significant effect of odour: The unpleasant odour condition was perceived as significantly more unpleasant than the no-odour condition ($p = .04$; see Figure 3(b)). Setting the pleasant odour as reference revealed that the unpleasant odour condition was perceived as significantly more unpleasant than the pleasant condition, $t(72) = -2.74$, $p = .008$. No other significant effects were retrieved. Please refer to Table 5SI of Supplemental materials for intensity and valence ratings LMMs' details.

Deontological responses increased while exposed to the neutral odour but not to pleasant and unpleasant odour conditions. The best fitting model for moral choice data (reference factor: utilitarian choice; AIC = 907.26; $X^2 = 53.83$, $p < .001$) resulted being the one including the odour

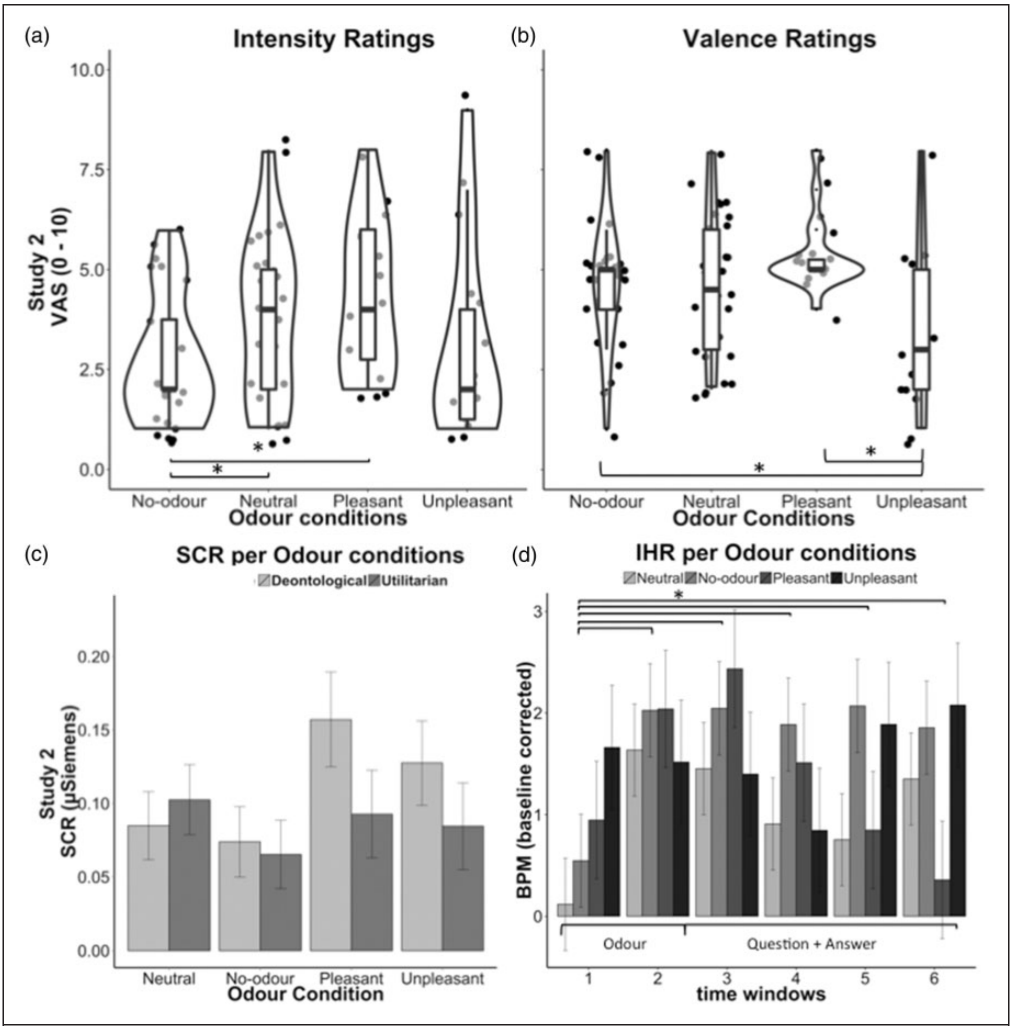

Figure 3. ((a) and (b)) Intensity and valence odour ratings for Study 2; (c) SCR per odour conditions; (d) IHR per time windows and odour conditions. ((a) and (b)) The black dots represent single data points, whereas the box-plot represents the interquartile range of each distribution, with the thick black horizontal bar corresponding to the median. Each box-plot is surrounded by a violin plot representing the smoothed distribution of data. Significant differences are indicated.

condition ($p < .001$), personal force ($p = .01$), intentionality ($p < .001$), benefit recipient ($p = .02$) and evitability ($p = .008$), the interaction of odour and each of these three factors, and the scores at STICSA ($p = .02$; Table 5). Deontological choices increase during the neutral odour condition compared to the pleasant ($p = .01$), unpleasant ($p = .005$) and no-odour conditions ($p < .0001$; reference factors: neutral odour and utilitarian choices). Changing reference in the odour condition factor did not show other significant effects. The increment in deontological moral choices was also promoted by the odour in interaction with the intentionality factor (reference factors: accidental). Relevant post hoc (*lsmeans* function) tests showed that participants gave more deontological responses when exposed to the neutral odour condition compared to no odour for accidental ($p = .01$)

Table 5. Summary of the Best Linear Mixed Effects Model on Moral Choices for Study 2.

Moral choices						95%CI	
Fixed effects with reference to neutral odour	β	*SE*	*z* value	*p* value	β exp	Lower	Upper
Intercept	3.06	0.94	3.25	**0.001**	21.311	3.369	134.809
No-odour	−2.00	0.52	−3.83	<**0.001**	0.136	0.049	0.377
Pleasant odour	−1.50	0.62	−2.42	**0.016**	0.222	0.066	0.753
Unpleasant odour	−1.87	0.68	−2.76	**0.006**	0.154	0.041	0.582
Personal force (*Impersonal*)	−0.93	0.32	−2.93	**0.003**	0.396	0.213	0.736
Intentionality (*Instrumental*)	0.17	0.33	0.51	0.608	1.187	0.617	2.283
Benefit recipient (*Self*)	−0.34	0.36	−0.94	0.345	0.714	0.354	1.438
Evitability (*Inevitable*)	−0.82	0.31	−2.65	**0.008**	0.441	0.240	0.808
STICSA *(Trait)*	−0.05	0.02	−2.34	**0.019**	0.951	0.912	0.992
Odour × Personal Force (*No-Odour, Impersonal*)	1.00	0.53	1.90	0.058	2.710	0.968	7.589
Odour × Personal Force (*Pleasant Odour, Impersonal*)	0.17	0.53	0.32	0.748	1.186	0.418	3.367
Odour × Personal Force (*Unpleasant Odour, Impersonal*)	0.47	0.58	0.81	0.416	1.606	0.514	5.020
Odour × Intentionality (*No-Odour, Instrumental*)	1.45	0.48	3.01	**0.003**	4.255	1.659	10.915
Odour × Intentionality (*Pleasant Odour, Instrumental*)	0.14	0.53	0.27	0.789	1.153	0.407	3.269
Odour × Intentionality (*Unpleasant Odour, Instrumental*)	0.08	0.57	0.13	0.894	1.079	0.351	3.319
Odour × Evitability (*No-Odour, Inevitable*)	−0.95	0.61	−1.56	0.118	0.386	0.117	1.271
Odour × Evitability (*Pleasant Odour, Inevitable*)	0.63	0.58	1.08	0.278	1.873	0.602	5.826
Odour × Evitability (*Unpleasant Odour, Inevitable*)	1.21	0.62	1.93	0.053	3.337	0.983	11.335

Note: β = estimate; SE = standard error; *CI* = confidence interval; β exp = exponential of β coefficient; STICSA = State Trait Inventory for Cognitive and Somatic Anxiety. Significant *p* values are reported in bold. Table shows model with utilitarian choice and neutral odour condition set as references. Contrast condition from the reference for categorical factors is reported in italic inside bracket.

dilemmas. Moreover, the likelihood of choosing deontological answers increased for personal (vs. impersonal) and avoidable (vs. inevitable) dilemmas as well as for lower STICSA scores.

SCR is greater for pleasant odour conditions. The best model (AIC = −446.02; L. Ratio = 11.97, $p = .06$) included the odour condition ($p = .08$), moral choice ($p = .46$), personal force ($p = .21$), intentionality ($p < .001$), benefit recipient ($p = .16$) and evitability ($p = .27$), the interaction of odour and moral choice (Table 6SI). Participants showed greater SCRs during the pleasant odour condition compared to the neutral ($p = .03$) and no-odour conditions ($p = .01$; setting pleasant odour as reference). The unpleasant odour condition showed a tendency for greater SCR as compared to no odour ($p = .06$). Even though the interaction between odour condition and moral choice is not significant, nominally, the pattern (Figure 3(c)) seems to be in line with the arousal elicited by the unpleasant odour but not by the neutral odour. Moreover, the likelihood that participants showed greater SCRs increased when dilemmas were accidental ($p < .001$).

IHR is reduced during the neutral odour condition compared to no-odour conditions. The best model (AIC = 27077.05; L. Ratio = 7.95, $p = .04$) resulted being the one including time ($p < .001$), odour condition ($p = .05$), personal force ($p = .53$), intentionality ($p = .78$), benefit recipient ($p = .58$), evitability ($p = .02$) and moral choice ($p < .001$; Table 7SI; reference factors: neutral odour). The likelihood to present a reduced IHR is greater for the exposure to neutral odour condition compared to the no odour condition ($p = .007$) while there is only a tendency between the neutral odour condition compared to the unpleasant condition ($p = .08$). Setting different reference factors does not reveal other significant effects. Moreover, the likelihood of presenting a reduced IHR increased when participants made deontological choices and when they answered to inevitable death dilemmas. Furthermore, a time effect is present. Relevant post hoc contrasts reveal that irrespective of the odour condition, the first time window, namely the odour onset, shows a significantly decreased IHR as compared to all following windows (all $p < .03$; Figure 3(d)).

Discussion

Study 2 was designed to investigate whether odour valance can affect moral choices. Taking advantage of the peculiar characteristics of ambiguous odours, which could either be perceived as pleasant or unpleasant stimuli (de Araujo et al., 2005), we keep constant the chemical stimulation while having participants differentially judge the pleasantness of the odour. As expected, the butyric acid was perceived as significantly more pleasant by the Pleasant group and significantly more unpleasant by the Unpleasant group. However, the intensity rating results show that there were significant differences between the three odour conditions.

Overall, we found that unpleasant and pleasant odours did not bias moral choices while the neutral odour did. Although this pattern of results does not overlap with any of our hypotheses, it leans towards the first alternative, suggesting that odour valence has no effect on moral choice. Specifically, smelling the neutral odour has a greater effect on deontological tendencies as compared to the pleasant/unpleasant odours and no odour. We advance that this result may emerge due to a novelty effect specific to the neutral odour (Bradley, 2009). Indeed, cedarwood oil may be an odour less familiar to our participants as compared to butyric acid. An additional, though not necessarily contrasting, explanation posits that for the odour valence effect to emerge on moral choice, higher concentration of the stimulus is necessary. Here, all odours were presented sub-threshold. As in Ugazio et al. (2012), during the olfactory condition characterized by lower sprays, the effect on moral behaviour is not evident. Furthermore, Study 2 confirmed the findings obtained in Study 1b showing that moral choices were biased towards deontological answers by the neutral odour presented sub-threshold.

The moral choice analyses confirmed the majority of predictors significantly increasing deontological choices found in Study 1b, the study in which the odour manipulation successfully differentiated conditions, as here in Study 2. Indeed, participants gave more deontological answers when the moral dilemma was described as personal (Christensen et al., 2014; Greene et al., 2004; Greene et al., 2009; Greene et al., 2008; Koenigs et al., 2007; Mendez et al., 2005; Moore et al., 2008; Moore et al., 2011; Moretto et al., 2009; Valdesolo & DeSteno, 2006; Youssef et al., 2012a) and avoidable (Hauser et al., 2007; Moore et al., 2008; Christensen et al., 2014).

As previously found in Studies 1a and 1b, participants' characteristics showed also an effect on moral choices. However, here the test scores significantly predicting deontological responses were a reduced trait anxiety (STICSA) – as expected from the literature (Starcke et al., 2008; Youssef et al., 2012a but see Starcke, Polzer, Wolf, & Brand, 2011 for negative result). The lack of a significant effect of autistic traits probably depends on the distribution of AQ scores across participants, which in this rather small sample is shorter ranging and more balanced than in Studies 1a and 1b.

In line with the idea that deontological choices are associated with reduced physiological activation as compared to utilitarian choices (Moretto et al., 2009), and that valenced odours induce increased arousal as compared to neutral odours (Bensafi et al., 2002), SCR data show a tendency toward lower arousal associated with the exposure to the neutral odour as compared to the pleasant odour. Consistently, the behavioural data on moral choice reveal a significant increment of deontological responses following the neutral odour condition. Specifically, greater arousal for deontological responses following the pleasant odour condition tends towards significance when compared to the arousal of deontological responses for the no-odour condition. The reduced arousal shown in connection with the neutral odour is in line with the electrodermal activity elicited by neutral novel stimuli, which is reported to be smaller than that provoked by novel pleasant and unpleasant stimuli (Bradley, 2009).

Moreover, even though we were expecting the cardiac activity to discriminate between pleasant and unpleasant odour stimulations (Bensafi et al., 2002), we did not found such result but only a cardiac output reduction during the presentation of the neutral odour. Our hypothesis to explain such effect is that the negative emotional state induced by the moral dilemmas and by making moral choices – evident in the generalized acceleration post dilemma processing – hid the odour valence effect on cardiac activity. We propose that the effect of the neutral odour only survives in light of its attention-grabbing power, which promotes cardiac activity reduction.

General Discussion

Our findings systematically evaluate, for the first time, the effects of sub-threshold olfactory stimuli in the moral domain. Odours presented sub-threshold are shown to affect, for instance, patterns of EEG activity (Lorig, Herman, Schwartz, & Cain, 1990), mood (Kirk-Smith, Van Toller, & Dodd, 1983; Zucco, Paolini, & Schaal, 2009) and social preferences (Li et al., 2007). This capacity, which makes olfactory stimuli relevant for moral decision-making, is related to the unique anatomical features of the olfactory system. Indeed, it is the only sensory system in which receptors project directly to the olfactory bulb and to the primary olfactory cortical areas (Carmichael, Clugnet, & Price, 1994) without the obligatory thalamic relay, that has been implied in conscious awareness (McAlonan, Cavanaugh, & Wurtz, 2008; Plailly, Howard, Gitelman, & Gottfried, 2008). This makes olfactory stimuli to be good experimental tools to investigate sub-threshold information processing (Li et al., 2007).

Besides opening an experimental window on the study of implicit information processing in the moral domain, the chemical senses are also ideally suited to evaluate the role that arousal and valence play in moral decision-making (Anderson et al., 2003; Winston et al., 2005). If, as we have seen, odour intensity matters, with moral choice being biased towards deontological responses when the odour is presented at a sub-threshold level, Study 2 might suggest that odour valence – contrary to expectations - did not affect participants' moral decisions. We propose that the odour valence effect might have been hidden by the attentional-grabbing effect of the neutral odour (Bradley, 2009), which may have been more novel to the participants as the pleasant/unpleasant odour. A further hypothesis is that the pleasant and unpleasant odours might affect moral choice only when presented in supra-threshold concentrations.

This lack of an effect of the pleasant/unpleasant odour on moral choice seems to be in contrast with previous literature on induced pleasant (Eskine, Kacinik, & Prinz, 2011;

Pastötter et al., 2013; Valdesolo & DeSteno, 2006) and unpleasant affective states and moral judgment (Cameron, Payne, & Doris, 2013; Case, Oaten, & Stevenson, 2012; Cheng, Ottati, & Price, 2013; Eskine et al., 2011; Harlé & Sanfey, 2010; Horberg, Oveis, Keltner, & Cohen, 2009; Johnson, Cheung, & Donnellan, 2014; Moretti & Di Pellegrino, 2010; Ong et al., 2014; Schnall et al., 2008; Seidel & Prinz, 2013; Ugazio et al., 2012).

However, some considerations are in order. First, previous studies were focused on moral judgment, while in our study participants were asked to make moral decisions. Even though these two labels have been used as synonyms in the past, it has recently been demonstrated that moral judgment and moral decision-making are two distinct psychological constructs, both referring to the system of moral norms (Sood & Forehand, 2005; Tassy, Oullier, Mancini, & Wicker, 2013). While in moral judgment tasks participants are asked to evaluate the *appropriateness* or the *permissibility* of certain actions, in moral decision-making tasks they are the main characters of a dilemma and, as such, they are responsible for the action chosen and for its moral consequences. So, it might be possible that the physical disgust amplification phenomenon theorized for moral judgment, actually it is not valid or not strong enough in the context of moral decision-making.

A third possibility is that the limitations of the present work might have obscured some effects. Although participants were carefully selected, the sample size is rather limited. This may have particularly affected highly variable measures such as IHR, whose variability is intrinsically important (Palomba et al., 2000). Second, in Study 2 only two odours were tested, suggesting that conclusions should be generalized with caution, while waiting for future studies to investigate the effects of wider samples of pleasant and unpleasant odours on moral choices. Third, dilemmas were designed in a way that the affirmative response was always the utilitarian option. This could have introduced a bias toward one option. Future studies should counterbalance the direction of the question, whenever possible.

In conclusion, our study points out that olfactory stimuli affect the processes underlying moral decisions by incrementing deontological choices and that this effect goes beyond the ability of the odour to induce disgust.

Supplemental Material

Supplementary material for this paper can be found at http://journals.sagepub.com/doi/suppl/10.1177/0301006616689279

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