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Review

Determining neurophysiological responses to physical and moral disgust elicitors–A systematic literature review

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ABSTRACT

Disgust is a common basic emotion with evolutionary roots in helping to avoid contaminants and illness. Moral disgust, however, is often reported in response to witnessing a moral violation or social boundary being crossed. Previous research has sought to understand if moral disgust is its own emotional state which derives from the more basic physical disgust, or if it is a blend of different emotions. To elucidate this relationship further, this review sought to systematically evaluate the methods in which research which has measured either physical disgust or moral disgust responses and identify common and separate physiological and neurological markers of these emotions. The review highlights that whilst there are common markers shared between physical and moral disgust, that this commonality depends instead on the type of moral violation or physical disgust elicitor. It is suggested that physical core disgust, and bodily moral or purity disgust are closely related, whereas physical animal-reminder disgust and socio-moral violations might elicit responses similar to anger or fear. The review recommends important considerations for future investigation of moral emotions, and highlights how stringent control of disgust elicitors is necessary to accurately measure the physiological and neurological markers of different types of disgust. Furthermore, the review highlights how other important considerations such as intention behind a violation and differences in perceived severity of different types of violation.

1. Introduction

Disgust is a basic emotion that many are used to experiencing. It is a powerful emotion that is generally universal across cultures and serves to protect from perceived contaminants that may be harmful to the individual, such as blood, vomit, and faeces [1,2]. As a result, this distinct emotion also carries its own distinct set of markers, including facial expressions, avoidant behaviour, and cardiovascular responses [3–5].

Due to these seemingly specific markers of what is described as physical disgust, or core disgust by Rozin et al. [2], it may seem a misrepresentation when an individual expresses a moralised disgust towards an event. To illustrate, the physical disgust response has been linked to mechanisms such as distaste towards an eaten substance, intended to identify the substance as potentially toxic [6], which is not usually the case with morality; a moral act doesn't necessarily require exposure to a toxin. Interestingly though, Vicario et al. [7] have demonstrated that greater levels of hunger reduce moral condemnation, perhaps in a similar way to how disgusting images elicited a reduced disgust expression in hungry individuals [8], suggesting that physical and moral disgust are indeed connected by similar processes.

Whilst such a response might not be typical in the case of morality, it has been shown that responses such as avoidant behaviour are exhibited when individuals report moral disgust [9]. This avoidant behaviour is akin to that of physical disgust; the emotion is an evolutionary response that serves to direct an individual away from contaminants. In the case of physical disgust, this may be vectors such as those stated previously; however, in the context of moral disgust, this may be an individual engaging in certain "wrongful" acts [10]. The action tendency of the emotion remains the same: stay away from, in this case, a social contaminant, which as Tybur et al. [11] suggest, may sustain an individual's standing in society, an important consideration for survival.

1.1. Morality, the moral foundation theory, and moral disgust

In order to assess any similarities and differences between physical and moral disgust, it is first necessary to provide a brief definition of what moral disgust is. Moral Foundations Theory (MFT; [12]) is a highly influential model of moral cognition and directly builds upon each of the models discussed in the previous section. MFT has its origins in Haidt's [13] criticism of rationalist approaches to moral reasoning and seeks to build on Shweder's [14] model of a set of core ethics which are universal

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Acronym key

EMG	Electromyography
CS	Corrugator supercilli
LL	Levator labii
ZM	Zygomaticus major
MF	Medial frontalis
HR/HRV	Heart rate/heart rate variability
EDA	Electrodermal activity
GSR	Galvanic skin response
SCR	Skin conductance response
SCL	Skin conductance level
ANS	Autonomic nervous system fMRI Functional magnetic resonance imaging
EEG	Electroencephalography tDCS Transcranial direct current stimulation
TMS	Transcranial magnetic stimulation
AI	Anterior insula
PI	Posterior insula
OFC	Orbitofrontal cortex
PFC	Prefrontal cortex
MFT	Moral foundations theory

across cultures. As a precursor to the theoretical model, Haidt provides this alternative definition of morality:

> "Moral systems are interlocking sets of values, practices, institutions, and evolved psychological mechanisms that work together to suppress or regulate selfishness and make social life possible… to suppress selfishness and form cooperative communities" ([15], p.70).

Here we see, rather than concrete moral reasoning which relies on judgements of harm or justice, the suggestion that all individuals draw upon the same core moral values which allow the maintenance of social bonds. These core values might be prioritised more highly by some cultures than others, for instance, higher moral importance might be put on clothing worn in cultures which mostly belong to a religious institution which endorses this idea [16], however, all cultures can be reverent about something which, as Shweder might put it, threatens the sanctity of the soul. Indeed, the MFT directly builds on some of Shweder's sets of ethics.

Moral disgust might be elicited by the violation of any of the moral foundations, as individuals often report feeling "disgusted" in response to moral violations. However, it has been argued that this classification is only a metaphorical use of the term "disgust" [17,18] and that the true emotion that is processed in response to the violation of many of these foundations is chiefly anger [19]. Literature addressing this metaphorical use has found specifically that purity violations alone predominantly elicit a disgust response [20]. This response is not altogether surprising, as the former four foundations could include such behaviour as a betrayal of trust in some respect, eliciting the more retributive emotion of anger [21]. Purity violations, on the other hand, may by definition include physical disgust reminders. For instance, one vignette used in Clifford et al. [22], "You see a man searching through the trash to find women's discarded underwear", describes a clear exposure to waste material, a possible contaminant. However, despite this physical disgust reminder, it may still be the case that few in society wish to be openly associated with an individual who engages in such behaviour and therefore wish to distance themselves from them. Additional evidence of discrepancies in emotional responses to different violation types is provided by Simpson et al. [23], who found that images depicting core disgust resulted in reduced disgust over time, whereas socio-moral violations increased disgust over time. As the images were designed to elicit socio-moral disgust (i.e. morally reprehensible acts), the same blend of purity and other moral foundations is found here, and it becomes difficult to determine precisely what type of violation was causing this increase in disgust, and why.

Despite this unclear differentiation between purity violations eliciting physical disgust or moral disgust, it could be argued that whilst moral disgust might not be elicited from exposure to physical contaminants, physical and moral disgust share common action tendencies, and are both elicited by stimuli that the individual wishes to avoid, due to either physical or socio-moral contamination. With these differences and similarities between the types of disgust in mind, it is important to note that many studies that have sought to compare and contrast the two types of disgust have often (1) noted coinciding or higher levels of anger [20,24], (2) relied on self-report alone to determine what an individual feels [19], (3) have included stimuli that have been shown to elicit emotions other than disgust [25]. It is therefore necessary to outline certain methodological parameters that could help to further distinguish these two emotions.

1.2. Physiological and neurological markers of disgust

One useful parameter to examine is the facial expression exhibited when disgust is being elicited. In their influential works, Ekman and Friesen [26], devised the Pictures of Facial Affect (POFA) and described the facial expression of disgust to be that of narrowed eyes (corrugator supercilli), and a raised upper lip and wrinkled nose (levator labii), which could be an evolutionary response to limiting exposure to contaminants by contracting the eyes and nasal pathways [11,27].

Measures such as facial electromyography (EMG), therefore, may be a useful inclusion in any methodology contrasting the two types of disgust, to determine if the prototypical disgust expression differs between the two. Furthermore, EMG has been used effectively to discern disgust responses from anger responses (e.g. disgust specifically elicits a levator labii response whereas anger typically does not), which may help to reduce errors brought on by metaphorical use in self-reported feelings of disgust by measuring responses to different moral foundation violations [20,28] and when comparing disgust to anger [29,30].

Another useful parameter to help compare the two types of disgust is the use of psychophysiological response measures such as heart rate (HR) and skin conductance response (SCR). Heart rate variability (HRV), for instance, is a beat-to-beat measure of fluctuations in an individual's heart rate interval which can provide insight into autonomic nervous system (ANS) activity, providing information such as possible stress and arousal levels. As such, it has been used to accurately distinguish different emotional states [31–33], suggesting the ANS response to different emotions may have their own signatures. This is consistent with Matsumoto and Ekman's model of basic emotions [34], wherein different cognitions and physiological changes might lead to a useful behavioural outcome or further scanning of the environment to update the emotional response. If this is the case, then HRV measures could be compared in core and moral disgust to see if they elicit similar responses, as well as differentiate these from other moral emotions such as anger. The HRV findings are supported by SCR, which too has been used to identify different emotional states [35,36]. SCR, like HRV, can provide insight into changes in ANS activity of an individual when emotional changes are occurring. These responses have been linked to emotional processing areas in the brain such as the amygdala and hippocampus [37,38], which in tandem have been linked to response to threats [39,40]. Disgust responses are the product of a perceived threat, a contaminant, and whereas disgust sensitivity has often been linked with heightened trait anxiety levels, disgust has been found to activate areas such as the amygdala independently from anxiety [41]. SCR, whilst often paired with other physiological measures [42–44], could provide further information about the ANS responses of both core and moral disgust. Therefore, methodologies that include physiological measures might provide important detail about the emotional effect of the processing of the two types of disgust.

Emotional responses via expression and ANS activity are both useful tools to gain insight into the physiological responses to disgusting stimuli and provide some information about neurological processes that might be occurring at this time. These associations can be further supported by specifically using neuroimaging techniques that can help to determine when and where these processes are occurring in the brain. As with the previously discussed methodologies, neuroimaging techniques have been used to accurately identify markers of different emotions, such as in the cases of electroencephalography (EEG; [45,46]) and fMRI, with a useful review on the latter provided by Phan et al., [47]. Disgust specifically has been associated with regions such as the orbitofrontal cortex (OFC; [25]), insula [48], amygdala, and anterior cingulate [49], and therefore studies that use imaging techniques to assess differences in activation between these areas would be very useful in highlighting any correlation between the disgust types. However, as Chapman and Anderson [50] point out in their detailed review on moral disgust, many of these studies have methodological shortcomings that might confuse or combine core and moral disgust. It is, then, necessary that an ideal methodological design will control for coactivation of physical and moral disgust regions through careful study design.

1.3. The present review

There have been a number of reviews that have addressed the topic of moral disgust and have taken the above considerations into account when detailing the findings of the current literature. The brilliantly useful review by Chapman and Anderson [50] should be a starting point for all to familiarise themselves with the phenomenon. A more recent review by Giner-Sorolla et al. [51] also provides an important overview of the theory, elicitors and action tendencies of moral disgust and the oft-confused moral emotion of anger and provides important considerations for the functions of moral disgust in a socio-moral context. Vicario et al. [52] give important details of how disgust processing might be affected in different neural regions through analysis of lesion studies, which helps to elucidate how disgust might serve to function in neurotypical individuals. However, at the time of writing, no systematic literature review that seeks to determine similarities and differences between moral and physical disgust across each of these methodological approaches yet exists.

It is important to acknowledge that some research (e.g., [53,54]) has proposed sexual disgust as a distinct domain alongside pathogen and moral disgust. However, sexual disgust is typically elicited in highly specific contexts, such as aversion to particular sexual acts or inappropriate partners, rather than across a broad range of stimuli. Previous research has suggested that these elicitors substantially overlap with either pathogen-avoidance mechanisms (e.g., concerns about disease transmission) or moral and purity concerns (e.g., violations of sexual norms or taboos; [9,55]). Consequently, much of the literature examining disgust elicitation has treated sexual disgust as reducible to these broader physical or moral domains, making it difficult to identify unique markers of sexual disgust independent of them. In line with this evidence, the present review focuses on physical and moral disgust, as isolating sexual disgust would require a level of situational specificity beyond the intended scope and theoretical coherence of the current analysis.

The aim of this systematic review is therefore to search the existing literature for studies that have utilised any of these methodologies, in either moral disgust, physical disgust, or both, and report the findings so that commonalities between the disgusts might be better understood. By doing so, it might be possible to determine if moral disgust is indeed its own, distinct emotion, separate from the basic emotion of physical disgust, or if any differences found between the two can be explained by coinciding cognitive processes. The research questions specifically are:

1) Does physical disgust differ from moral disgust on physiological or neurological measures?
2) Are any differences found reliable, or might they be the product of differences in methodological design?
3) Through these caveats combined, is moral disgust a distinct emotion from physical disgust?

As physical disgust and moral disgust are suggested to be so closely related, it is necessary to essentially complete two reviews in order to answer the above questions. By reviewing the literature for each type of disgust, determining similarities and differences between them will be much more efficient, as well as addressing why this might be and highlighting any caveats for this. The aim of this chapter is therefore to catalogue and review all relevant research on the markers of physical and moral disgust when these targeted emotions are elicited.

2. Methodology

2.1. Search strategy

The search was conducted by the principal author using EBSCOhost (encompassing 23 separate databases, see Appendix A), Scopus, Wiley Online and Cochrane Library databases between 15/6/21 to 1/7/21, and an updated search was run on 1/8/22. All articles from inception to 1/8/22 were included in the search. Two separate search terms were used; the first for physical disgust and the second for moral disgust, each designed to find articles that specifically utilise any or all of the methodologies outlined previously. Search terms can be found in Appendix B. Exclusion criteria at the search stage were limited only to peer-reviewed articles, in English, with a sample that included only adults (over 18+). The reason for the age limitation is that both morality and disgust development are in flux in children and adolescents [56,57]. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The combined total of papers found was 642 (363 moral, 279 physical).

2.2. Inclusion and exclusion criteria

The titles and abstracts of the retrieved papers were assessed to identify potentially relevant studies with the following criteria:

a) The study samples were only adults (aged over 18 years)
b) The study contained one or more of the following methodological measures: EMG, heart rate/HRV, skin conductance response/galvanic skin response, neuroimaging techniques, observed behavioural responses.
c) The study focused on the elicitation of moral or physical disgust, and not, for instance, the recognition of disgust in others, e.g., facial expression recognition.

Both the principal author (OH) and a research assistant (PE) screened each of the titles and abstracts for inclusion, and uncertainties and disagreements were resolved through team discussion. Of the initial 642 papers, 61 relevant papers, based on content in the titles and abstracts, were retained for further evaluation. Inclusion in the final sample was then confirmed by a team of three reviewers (OH, PE, AY) who independently checked the full text of all retrieved articles. Of these 61 papers, the reference lists were searched, and another 6 studies of potential relevance were highlighted for further review. Of the 67 total papers (47 moral disgust, 20 physical disgust), 23 were excluded for the following reasons (22 from moral disgust, 1 from physical disgust):

a) 1 where morality was not specifically measured or manipulated
b) 1 was a registered trial with no associated data
c) 4 focused on the recognition of disgust, not the experience of the emotion itself

d) 7 didn't focus specifically on moral disgust measurement but broader moral judgement
e) 10 didn't have sufficient focus on physiological aspects of disgust.

A flowchart detailing the systematic review process can be found in Fig. 1.

Following the collection of the relevant papers, a quality assessment was undertaken for each, using the AXIS critical appraisal tool [58]. To be included in the final review, all relevant papers also had to meet the above inclusion and exclusion criteria, as well as pass the quality assessment. No relevant papers were found to be of insufficient quality, so all 44 (after exclusion) were included in the final review. Full quality assessment tables can be found in the supplementary material.

3. Defining disgust – what psychobiological markers can reveal about core disgust responses

As this review aims to compare markers of core disgust to those of moral disgust, an obvious starting point is to establish what the common markers of physical disgust are. Following similar methodology to Chapman and Anderson [50], any relevant studies have been categorised under headings that represent the dominant methodology used to attain their data. These headings are also informed by the different possible markers of emotional responses as outlined in the aims of this review.

In addition to these categorisations for found research, each of the studies in Table 1 is provided with a symbol to signify what the findings reveal about the nature of physical disgust (found in the key for Table 1).

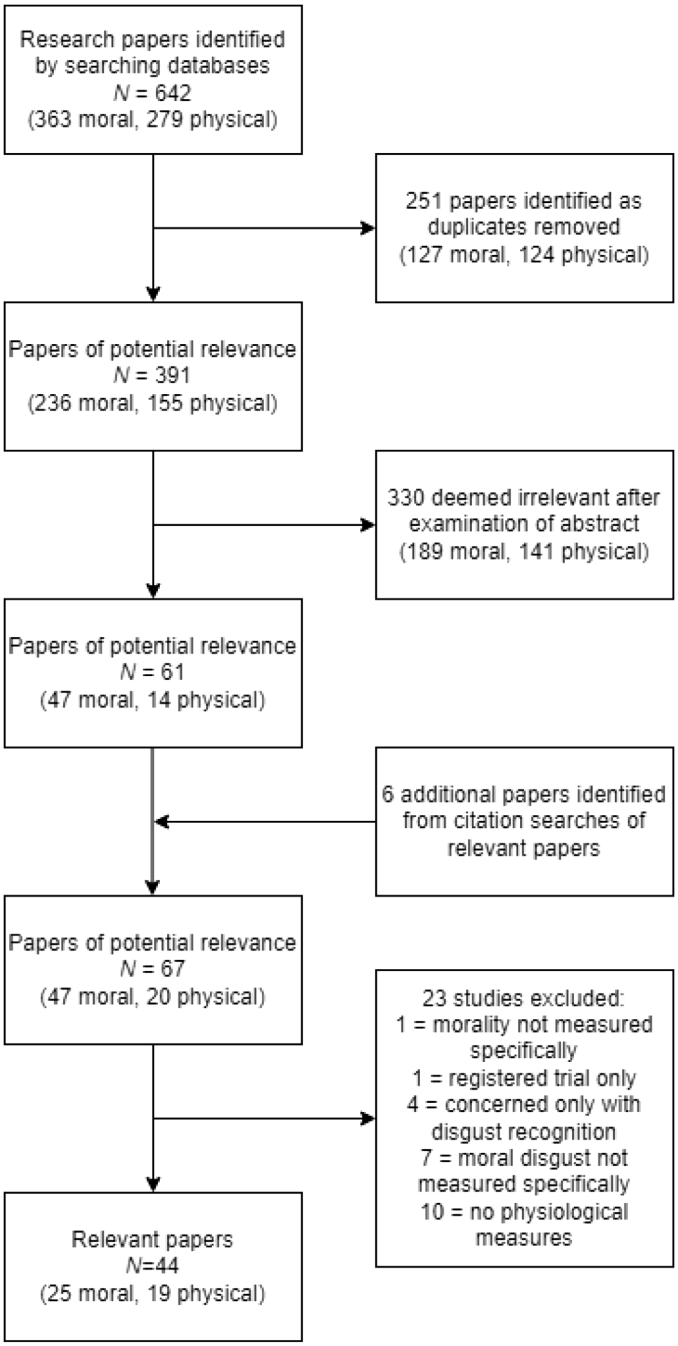

Fig. 1. Breakdown of review search strategy.

Table 1
Summary of studies aiming to measure responses to physically disgusting stimuli.

Study	Sample size	IV	DV	Results brief	Summary	Notes
EMG studies						
[59]	18	Solution taste	Facial expression Self-report	+	Upper-lip raising but nor nose-wrinkling was associated with a distaste (or disgust) expression.	Participants might not have been ignorant to design.
[61]	80	Disgust inducing video clips	EGG EMG (orbicularis oris, levator labii, and corrugator supercilli) HRV Self-report	±	In self-report and EMG measures, animal and core disgust appeared to both show increased experience for these scenarios. However, core disgust was found to decrease gastric activity and animal reminder decelerated HR and increased HRV.	Animal reminder stimuli may be inherently moralised, or induce empathy, making distinction here difficult.
Physiological studies						
[62]	25	Inclusion exclusion in social game Disgusting smells Painful stimuli	Self-report, SCL, HR & respiration	+	Following exclusion, pain subjection modified physiological responses, but disgusting smells did not. This suggests shared neural pathways by disgust and pain do not generalise to a negative social experience	No comparison with other negative emotions
[63]	78	Video clips	HR Self-report	-	Reported disgust highest in response to food, sexual and physical films. Negative sexual films increased HR whereas negative physical films reduce HR.	Disgust not a specific DV
[64]	51	Disgust inducing video and audio clips	CV measures	±	Disgust induction generates a consistent CV response, but the nature of this response is dependent on the context of the induction. Here, audio scripts resulted in decreases in electrical inotropy, mechanical inotropy, and cardiac contraction. The film resulted in increased diastolic blood pressure, which indicates an increased alpha-adrenergic tone	No comparison with anger and fear
[65]	42	Picture rating task	HR SCL Self-report	+	Disgust and arousal have an effect on negative affect symptom reporting, but there is no physiological support for this here.	No comparison with other emotions.
[66]	60	Video clips	EMG (m. corrugator and m. levator labii) ECG SCL Self-report	+	Participants showed increased parasympathetic activity of both the cardiac and the digestive components of the autonomic nervous system (ANS), together with increased sympathetic activation of the cardiac system. ANS responses were independent of subjective disgust and individuals' habitual disgust propensity or sensitivity.	No comparison with other emotions.
[67]	12	Video clips	SCL FT HR BVP	+	Disgust can be reliably measured and distinguished from other emotions based on physiological measures	Content of stimuli not clear to determine heterogeneity from other emotions.
[68]	89 (study 2) 42 (study 3)	Disgust scale Disgust inducing videos	Behavioural measures EMG & HR Self-report	±	The three core disgust types are significantly associated, though seem to induce different physiological effects. Core disgust was significantly related to increased physiological responding during exposure to vomit, while animal-reminder disgust was specifically related to physiological responding during exposure to blood. This may represent different avoidance mechanisms e.g. incorporation, defence and disease)	No comparison with other emotions.
[69]	56 (study 1) 50 (study 2) 66 (study 3)	Vignette rating task	Self-report (study 1) ECG (study 2)	±	Disgust is felt more subjectively to strangers than familiar agents. This is supported by physiological and behavioural data. This suggests the bearer of disgust has an effect on how disgust is felt.	No comparison with other emotions. Some sentences might be moralised.
[70]	100	Video clips (food related, disease related)	HR SCL Self-report	±	Disgust responses were significantly different from neutral and other negative responses, demonstrating a physiological effect of disgust. The response between disgust types differed, perhaps reflecting different avoidance mechanisms.	Potential perceived harm moralised disease stimuli
[71]	74	Image recognition task (Food disgust, non-food disgust, food control, negative emotion control)	Body temperature Saliva production Self-report	+	Body temperature was significantly higher in the disgust groups compared to the negative group, but not when compared to the control group. TNF-a and albumin levels increased in the combined disgust groups compared to the combined control groups, indicating a heightened immune response. These levels also	-

(*continued on next page*)

Table 1 (*continued*)

Study	Sample size	IV	DV	Results brief	Summary	Notes
					correlated with an increase in body temperature. Overall, these findings suggest that disgust triggers an anticipatory stress response, activating the immune system, likely to prepare the body for combating perceived contaminants.	
[72]	60	Disgust inducing scripts	Saliva production EMG ECG Blood pressure SCL	+	Disgust type did not appear to affect physiological responses on any of the measures.	Potential moralised disgust in the animal reminder condition. No contrast with other emotions
Study	**Sample size**	**IV**	**DV**	**Results brief**	**Summary**	**Notes**
fMRI studies						
[73]	12	Image rating and imagination-based mood induction	fMRI Self-report	+	Involvement of the insula and basal ganglia (caudate and putamen) in the interoceptive experience of disgust as has previously been found in the perception of disgust. The seeing and feeling of disgust may be mediated by a shared neural circuitry.	No comparison with other emotions.
[74]	12	Visually disgusting videos	fMRI HR Self-report	±	Core and animal-reminder disgust elicited subjective disgust. Gastric and cardiac responses were linked to the intensity of disgust. Insula activation was increased in both disgust types in different sides of the brain.	-
[75]	15	Scent rating task	fMRI	+	Stronger BOLD signals within the anterior cingulate gyrus, insula and motor areas were found during negative compared to neutral stimulation and are considered to represent an attempt to down-regulate the strong emotional experience and the organisms' preparation for withdrawal, respectively.	No comparison with other emotions.
[76]	59	Word-pairing task	fMRI activity Self-report	+	Disgust word-pairs recalled more than fear. Greater amygdala activation in response to disgust.	No physiological measures to monitor differences in reported arousal
[77]	99	Disgust vignettes	VBM (GMV)	±	Only core disgust shows an association with the GMV of the gustatory cortex (insula), whereas the reactivity to other disgust areas is linked with cognitive control areas (DMPFC and the DLPFC).	No comparison with other emotions.
[78]	20	Scent/pain rating task	fMRI activity GSR Self-report	-	Suggest that the insular cortex encodes prospective aversive events in terms of their modality-specific features, and whether they match with subsequent stimulations, so is not unique to disgust.	No comparison with other emotions.
EEG study						
[79]	43	Visual search task	EEG Self-report	+	Fear processing of threat occurs more quickly than disgust. The suppressed sensory perceptual and attentional processing of disgust information, is akin to the central ecological function of disgust to minimize contact with contagious objects to avoid contamination and disease	-
[89]	25	Preferential looking task	Eye-movement	+	Oculomotor disgust avoidance isn't disrupted by an antiemetic alone, it requires incentivised exposure to change the attitude towards disgusting stimuli.	No comparison with other emotions

Results key:
+ = findings suggest homogeneity of physical disgust responses;
± = findings suggest mixed physical disgust responses;
- = findings suggest physical disgust responses indistinguishable/shared by other emotions

To illustrate, some research considers the physiological responses of physical disgust to be homogenous, regardless of the nature of the stimuli used. For example, using the data from Chapman et al. [59], if used to determine a consistent physical disgust response, it must be assumed that distaste elicits the same facial muscle responses as a bad smell. Whereas this consideration was not part of the study's aims, for the sake of this review, it is important to keep such assertions in mind when determining the reliable markers of physical disgust. Furthermore, as described by Rozin et al. [60], physical disgust can be elicited by animal-reminders, contaminants, interpersonal vectors, and socio-moral stimuli (though the latter category is reserved for the section reviewing moral disgust here) and some methodologies may or may not examine these different elicitors at the same time in order to compare disgust responses between them. To further examine this consideration, it is important to note where research has found differing responses dependent on the nature of the stimuli. It is also necessary to highlight

research where disgust responses have been found to be shared with those of other emotions or cannot be distinguished from other emotions. This may be due either to shared activation or a methodological limitation, though in any case is also of great import when determining reliable physical disgust responses.

The analysis in this review therefore explores what the findings of different measurement techniques can explain about the nature of physical disgust as a whole. As a result, the following analysis includes studies where physical disgust responses alone, and not moral disgust, have been measured.

3.1. Markers of physical disgust

Evolutionary theories of emotion have resulted in methodologies that argue that the development of emotional expressions in response to environmental threats serves to influence individual behaviour to improve survivability [80,81]. Indeed, this theory has seen support from more recent research such as [1], and [11], with the latter describing how disgust can be instrumental in the avoidance of contaminants, and even mate selection. Examples of how this might manifest, such as in facial expressions, are given previously in this review.

However, emotional expression may not always tell the whole story of how a stimulus is being processed. Self-report and facial expressions, especially if known to be recorded by the participant, could invite response bias. Therefore, following seminal theories from evolutionary [82,83] and appraisal [84] models, it is important to determine if physiological responses to disgusting stimuli might provide more information about emotional processing. This is important for two main reasons, nicely represented by each of the former models. From an evolutionary standpoint, we can potentially determine if heart rate, sweat production, or gastric responses have a specific signature for disgust, if this differs across disgust types, or even is similar for all emotions. From an appraisal standpoint, it could be possible to determine if reported or observed emotions correspond with an expected physiological signature, theoretically and historically, and if not, why this might be. Furthermore, there exists research which suggests shared neural pathways in negative experiences, such as in pain and disgust [85], and it is necessary to investigate designs which have specifically recorded neurological responses to disgust elicitation.

One paper included in the review of physical disgust elicitation used a methodology of which the focus was not easily categorised as using physiological or neurological measures. Behavioural measures, in the context of this review, refer to the measurable, observable effects on an individual's behaviour after being exposed to a physically disgusting stimulus. Self-report could be classified as such; however, as previously referred to in this review, self-report alone is not considered to be adequate to be indicative of emotional processing.

The search terms for the current review found only two articles that were specifically focused on measuring induced disgust via EMG responses. It is worth noting that the search returned many articles that aimed to use EMG to measure responses to disgust *recognition* in others (e.g. [86]); however, reviewing such methodologies was not the aim of this paper.

In reviewing the literature contained in Table 1, clear markers for physical disgust begin to present themselves. Chapman et al. [59] and Shenhav and Mendes [61] provide evidence of facial expressions representing disgust processing, specifically through activation of the levator labii and corrugator, matching seminal theories on disgust expression [82]. Whilst not their focus, these patterns are generally repeated in other designs in this review too. There are exceptions to this pattern, which might manifest as reduced comparative corrugator activity [66,68,72].

Physiologically, there again seems to be a clear pattern of disgust responses. These appear to depend on the type of physical disgust stimulus eliciting the response, with contamination disgust resulting in reduced HR and increased GSR responses in video designs [61,63,64,67,68,70], vignette tasks [69], and odour elicitation tasks [62], whereas animal-reminder disgust conversely appears to increase HR [63,68,74]. There are exceptions to this effect [65,66,72], which generally might have to do with the homogenisation of disgust types in designs. Furthermore, there is evidence for dysrhythmic gastric activity and increased salivary immune responses in response to core disgust [71].

It is suggested by the current authors that differences in facial activity and physiological response could depend on the type of disgust being elicited. Specifically, it's possible to see how core and contamination disgust from stimuli such as rotten or bitter food might translate to an initial disgust response, whereas some may find that the drawing of blood, for instance, triggers something of a fear response, or empathy, as with Rohrmann and Hopp [70], triggered by perceived harm. Therefore, animal-reminder disgust might intrinsically be associated with moral foundations which are more readily associated with emotions other than disgust, such as anger, and not representative of a pure disgust response.

Neurologically, the insula is shown to be the most commonly activated region of the brain in the works reviewed [73–75,77,78,87]. Furthermore, the PFC and OFC are shown as common areas of neural activation in response to disgust [75,77] along with the amygdala, thalamus, and hippocampus [73,76,78,79]. The findings suggest that the experience of induced physical disgust recruits various regions of the brain. These regions generally engage in threat identification and differentiation, and preparatory responses for avoidance of contamination of a perceived disgusting threat.

Similarly to the physiological measures discussed previously, in Borg et al. [87], subjective reports of disgust did not differ between disgust domains of core and animal-reminder and also demonstrated shared activation of the insula. This might suggest that, whilst both initially disgusting, these domains might recruit different neurological regions to form a distinct avoidance response, or disgust recognition, such as increased empathy in response to bodily information [88]. Physiological and neurological responses to different types of disgust do not appear to be homogeneous.

Finally, it was found in Nord et al. [89] that the avoidant action tendency, demonstrated by gaze-avoidance, produced by disgust induction could be attenuated, but only when physiological responses to disgusting stimuli are reduced by pharmacological means, and with incentivisation. This suggests that behaviour in response to disgusting media might be influenced by the physiological findings cited earlier; however, no such parallel could be drawn for neurological measures in this review.

Altogether, we can see that in physical disgust, there generally appears to be a pattern of distinct responses not typically seen in other emotional elicitation such as increased levator labii activity, as well as other markers such an increase or decrease in HR (dependent on the type of physical disgust targeted), increased EDA, and an avoidant action tendency.

4. Is moral disgust disgusting? – the psychobiological markers of moral disgust

The previous section of this review has ascertained that physical disgust appears to have clear markers that signify its processing in an individual. Taken alone, the physiological, neurological, and behavioural findings might not be able to fully distinguish themselves from other negative emotions such as fear; however, when combined, it becomes clearer what represents physical disgust's markers.

With what defines a physical disgust response in mind, it is now possible to apply the same scrutiny to methodologies that have aimed to elicit and measure moral disgust. By doing so, it will be possible to determine, firstly, if moral disgust has its own distinct set of markers, and if these distinguish it from physical disgust, but also, vitally, the often arguably confused emotion of anger [20]. Secondly, the findings of this review of moral disgust methodologies might elucidate the best methods of recording responses to morally disgusting stimuli.

Table 2
Summary of studies aiming to measure responses to morally disgusting stimuli.

Study	Sample size	IV	DV	Results brief	Summary	Notes
EMG studies						
[90]	108	Photos of in- and out-group politicians with and without moral violation text alongside	EMG activity (levator labii & corrugator supercilli), SCL, and self-report	+	Physiological data and self-report data suggest participants are more disgusted by out-party leaders than in-party leaders, but the researchers found no correlation between these data.	EMG findings based on exploratory analysis. Moral violations tend to focus on harm or fairness foundations.
[91]	107 (30 NZ, 40 HK, 37 UK)	90 vice and virtue moral foundation scenarios	EMG activity (m. levator labii, m.corrugator supercilli, m. zygomaticus major, m. medial frontalis) Self-report	+	Suggests a cross-cultural levator labii and corrugator response for moral disgust violations.	Assumes primarily purity violations elicit moral disgust. No comparison with core disgust.
[28]	39	Moralised statements	EMG activity (levator labii, corrugator supercilli) Self-report	+	Facial disgust was highest in response to purity violations, followed by fairness violations. In contrast, harm violations evoked anger expressions	-
[92]	16	Solution tasting Image viewing Unfair economic game	EMG activity (levator labii) Self-report (disgust and sadness)	+	Facial disgust response shown for distaste, physical disgust images, and moral violation of fairness.	No comparison with other moral foundations.
[93]	27	Sociomoral norm-violating vignettes	EMG activity (levator labii, corrugator supercilli) EDA activity Self-report	±	Higher self-reported moral outrage concurrent with greater levator activity suggests higher levels of moral disgust. EDA activity did not reflect this.	No comparison with core disgust. No direct measure of moral disgust - have to assume EMG activity reflects this.
[94]*	16 (study 2a), 36 (study 2b)	Physical purity violation vignettes (study 2a) and religious thought violations (study 2b)	EMG activity (levator labii, corrugator supercilli) Self-report	+	Purity violations with physical disgust content resulted in higher reported disgust and levator activity. The heretical thought-based purity violation did produce the same response to disgust.	No comparison with non-moral physical disgust. No comparison with other moral foundations. Corrugator findings non-significant.
[95]	49 (study 1) 46 (study 2) 48 (study 3) 40 (study 4)	Physical disgust, moral, negative and neutral images, as well as images of obese individuals	EMG activity (levator labii, corrugator supercilli, zygomaticus major) Self-report	-	Physical disgust shown to increase levator activity, but this not shown to be the case for moral disgust. Obesity also did not produce EMG activity similar to a physical disgust response.	Moral disgust items shown depicted mostly harm violations Assumes obesity is seen as a bodily moral violation
[30]	90	75 images of which 1 of 3 categories shown (moral, negative non-moral, neutral) dependent on induced mood condition (disgust, anger, neutral)	EMG (levator laabi, corrugator supercilii) Self-report	+	Disgust induction appears to increase physiological disgust responses to moral stimuli, suggesting a shared response. This response is not shown in anger induction.	Differences in mood induction may lead to variance
[96]	21 (study 1), 21 (study 2)	Moral transgression scenarios	Heart rate Self-report	+	Disgust response to moral violations results in decreased heart rate. No effect is found for moral anger.	Mixing of intentionalities which isn't controlled for No comparison to physical disgust
[97]	40	Physical or moral disgust induction via 3-minute scripts	HRV Self-report	+	This suggests that core disgust increases PNS activity and decreased ANS activity in moral disgust. Moral disgust is physiologically distinct from physical disgust and may be closer to anger/indignation/ contempt.	Only one moral violation for each type of disgust used
[98]	119	Physical disgust (body envelope and body product) and moral disgust video clips	HR SCL EMG Self-report	+	All disgust types seemed to differ in responses. Sociomoral disgust appeared to require more delayed, considered responses to violations.	Habituation of stimuli may be a factor here. Only one example for each type of disgust used
Neuroimaging studies						
fMRI studies						
[25]	13	Moral transgression vignettes	fMRI activity	±	Many overlapping regions in both physical and moral disgust, though some notable differences between the two.	Moral transgression might be mixed with physical disgust No comparison to other moral emotions - such as anger
[99]	22	Lexical decision task with moral disgust, matched disgust, high disgust, moral anger, neutral and scrambled vignettes	fMRI activity Self-report	+	Physical disgust and moral disgust are not dissimilar in regions that are activated, and any additional disgust sampled from self-report measures is	Vignettes include mixed moral problems i.e. some contain both purity and harm violations

(*continued on next page*)

Table 2 (*continued*)

Study	Sample size	IV	DV	Results brief	Summary	Notes
					characterised more by a moral anger response.	
[100]	38	Moral judgement task with vignettes	fMRI activity Self-report	+	Suggests the dorsal pFC is associated in all moral judgements. Each type of moral judgement (disgust, harm, dishonesty) elicits its own specific response characterised by different neural regions. These regions are engaged differentially depending on the transgression.	No comparison with physical disgust
[49]	50	Moral judgement memory and recall task	fMRI activity Self-report	+	Demonstrates shared and unique region activation in response to physical and moral disgust. Also highlights differences between different types of moral disgust.	Physical disgust comparison here not non-moral - contains purity violations.
[101]	33 (study 1), 27 (study 2)	Moral judgement and scent/ pain rating task	fMRI activity GSR Self-report	+	Insula activity is associated with disgusting scents but not pain. Exposure to moral violations enhances the response to core disgust stimuli as shown by GSR and insula activity. This effect is mediated by activity in the PCC suggesting a role in assessing acceptability of moral violations.	Moral dilemmas rather than moral violations might result in different responses.
[102]	29	Moral judgement task with vignettes	fMRI activity Self-report	+	AI activation to moral transgressions appears to involve more emotion regulation than PI activation when considering strangers. PI may be more involved with initial moral processing and the AI more reasoned and introspective.	No comparison with physical disgust Findings could be due to other moral emotions such as anger
EEG/ERP studies						
[103]	20	Lexical decision task for words vs. non-words in physical disgust, moral and neutral categories	EEG activity (EPN, N320, N400, LPC) Self-report	±	Appear to be distinct neural processes between cognitive processes of disgust types. Physical disgust modulated early and late ERP activity Moral disgust only modulates late ERP activity. Frontal negativity is related to general disgust.	Based only on word recognition, might not induce the disgust emotion.
[104]	12	Moral judgement task with vignettes	ERP activity Self-report	+	Morality and disgust appear to elicit activation at different times. Moral violation recognition may precede disgust recognition.	Early ERP activity doesn't necessarily pertain only to moral disgust, but morality generally. Results could be due to anger for instance.
[105]	16	Moral judgement task with vignettes	ERP activity Self-report	+		
[106]	18	Oddball task with deviant moral images (physical disgust, moral disgust and neutral)	ERP activity	+	Physical disgust triggers stronger early and late brain responses compared to moral disgust, indicating more automatic processing. However, moral disgust elicits higher mid-latency responses, possibly reflecting the cognitive processing of social norm violations.	No comparison with other emotions
Study	**Sample size**	**IV**	**DV**	**Results brief**	**Summary**	**Notes**
tDCS/TMS studies						
[107]	37	Moral judgement task with vignettes Word fragment completion task	tDCS HR Self-report	+	Indirect anodal tDCS stimulation of the insula by T3 resulted in higher ratings of moral wrongness and HRV patterns consistent with physical disgust.	Topographical specificity of tDCS is a factor. No comparison with physical disgust.
[112]	36	Moral judgement task with vignettes Word fragment completion task	tDCS HR Self-report	+	Indirect anodal stimulation of the insula by T3 resulted in higher ratings of moral wrongness and HRV patterns consistent with physical disgust, this pattern was reversed for cathodal tDCS.	

(*continued on next page*)

Table 2 (*continued*)

Study	Sample size	IV	DV	Results brief	Summary	Notes
[108]	13	Emotion response (indignance) to moral and non-moral vignettes	TMS (tongue and hand MEPs Self-report	±	Reduced tongue MEPs and increased hand MEPs may support evolutionary origins of disgust avoidance which is common in physical and moral disgust	Have to assume indignance does reflect feelings of moral disgust
Behavioural studies						
[109]	105 (study 1) 107 (study 2) 235 (study 3)	Morally disgusting films (study 1) Moral violation writing task (study 2) Moral violation radio news story (study 3)	Consumption behaviour after watching clips	±	Moral violation conditions resulted in less consumption in participants, indicating a disgust response similar to physical disgust to reduce oral inhibition.	Different moral foundations used throughout. No comparison with physical disgust. No control for anger.
[110]	33	Audio of moral vignettes	Facial expression Self-report	-	Anger more commonly felt in response to moral transgressions.	Methodology could invite participant bias. No control for physical disgust
[111]	222 (study 1) 182 (study 2)	Hand grip strength	Disgust sensitivity (pathogen, sexual, moral disgust)	±	HGS negatively correlated with pathogen and sexual disgust sensitivity, but not moral disgust, when age and BMI were controlled for, and in the second study, when self-perceived attractiveness, testosterone, cortisol and other health markers were controlled	Moral disgust refers to non-purity definitions

Results key:
+ = findings suggest support for distinct moral disgust response;
± = as above but moral disgust or condemnation is not measured explicitly by self-report;
- = findings do not find support for distinct moral disgust response
* = only select relevant studies are included from the paper

In a manner similar to the previous section on physical disgust, the papers focusing on moral disgust are shown in Table 2. Again, these have been assigned a symbol within the table, signifying to which degree they suggest a distinct response signature for moral disgust, where this distinction is more ambiguous (or not expressly measured by asking about moral condemnation or moral disgust), and finally, if the findings do not suggest a distinct set of markers for moral disgust. As before, these papers have been critically evaluated, and the main findings are outlined below, arranged under subheadings that best reflect the main methodological approach used.

The rationale for the inclusion of each of these categories is generally the same as their physical disgust counterparts. With each of these sections, it is important to determine if moral disgust is represented by markers that match those of physical disgust. A more detailed analysis of the similarities and differences between the findings in each physical and moral disgust will be made later in this review.

4.1. Markers of moral disgust

In a similar vein to the first half of this review, patterns of moral disgust do tend to become apparent.

In each of the EMG studies of this review, every one of the papers analysed data collected from levator labii and corrugator supercilii sites, typically expected to represent disgust and anger responses, respectively. Some designs analysed zygomaticus major data [28,91,95], and one the medial frontalis (Buchtel et al.), though data collected from these sites was either non-significant or in the case of Buchtel et al., represented decreased activity, i.e., less smiling than normal, which may be due to a negative response of purity content, though this contrasts with FACS coding data from Franchin et al. [110]. Generally, greater levator labii activity was associated with higher reported disgust, in response to purity violations (though not religious purity, i.e., [94]), whereas anger was typically represented by greater corrugator supercilii activity. It is also worthwhile to note that this pattern was typically resilient to differences in elicitation method. Interestingly, greater corrugator supercilii activity was not recorded in response to loyalty/fairness violations in Bakker et al. [90], nor in fairness violations in Krumhuber et al. [93]. Furthermore, in one case, greater corrugator supercilii activity was observed in response to purity (body envelope) violations in Rubenking and Lang [98], though this may have been due to differences in level of arousal between conditions. Perhaps the most useful finding in terms of generalisability of EMG approaches to investigating moral disgust, is from that of Buchtel et al., which suggests different cultures may have different facial expressions in response to moral violations, and this is vitally important to consider when comparing responses across cultures.

Physiologically, the findings are somewhat mixed. Generally, it appears that moral violations with a physically disgusting element tend to reduce HR [96,98] and increase HRV [107,112], whereas anger was associated with an increased HR [96]. The reverse pattern was observed in Ottaviani et al. [97]; however, this may have been due to power dynamics in the morally disgusting stimuli (i.e., "consensual" incest between a parent and child may still involve manipulation of the minor), and due to this be more representative of a harm, and thereby angering, violation. GSR/SCL activity was more mixed, with evidence for increases and decreases in GSR, dependent on the type of bodily-moral violation, i.e., body envelope vs. body products, with the latter increasing GSR activity and the former reducing it. Sharvit et al. [101] also found increased SCL activity when moral violations were presented along with a disgusting olfactory stimulus. It may be that this isn't classified as moral disgust per se, but does reveal that physical disgust coupled with moral violations increases GSR activity. Finally, Krumhuber et al. [93] and Bakker et al. [90] found no effect on GSR/SCL activity, and this may therefore be best used as a tertiary measure after other behavioural and physiological measures (such as HR/HRV).

Neurologically, focussing first on imaging methods, many of the studies reviewed here note activation in the OFC and frontal gyri of the PFC in physical and moral disgust [25,49,99], though Schaich Borg and

colleagues note that there was a preferential activation for sexual disgust here. Other areas of note include the PCC [100,101] and ACC (Sharvit et al.), with the PCC implicated in the processing of moral content of scenarios, and the ACC in the processing of disgusting content [113]. Other main areas of interest in disgust and moral disgust research are the insulae. Whilst activation has been reported in many studies for the AI and PI [25,49,99–102], Moll's and Schaich Borg's papers suggest AI activation did not occur in physically disgusting scenarios, whereas Oaten suggests conversely that this activation did not occur in moral disgust. A reason for this may be that despite a stringent separation of conditions, the moral disgust stimuli in Oaten et al.'s task also contain references to harm and care violations intertwined with the purity violations, so the moral disgust response here might not be as pure as intended. However, it is useful to understand that there appears to be some shared activation of the AI across disgust types. This is highlighted by Ying's study, which differentiates activation of the AI and PI between someone close to an individual (e.g., mother) and a stranger, respectively. Interestingly, Ying's study also highlights greater connective activity between the AI and PCC in the mother condition (i.e., more morally reasoned responses), and greater connection between the PI and ACC in the stranger condition (i.e., processing disgust more readily).

It is important to note that the processing of physical and moral disgust has some neural overlaps. This is also the case with anger, a closely related emotion to moral disgust, which, in areas such as the thalamus, PCC and PFC, all contribute to socio-moral reasoning. Whilst there may not be a central control centre for the processing of moral disgust, it is useful to know that there are similarities and distinctions between emotions connected to it.

From the perspective of papers employing EEG/ERP methodologies, the four reviewed here all assessed processing times of moral vs physical disgust, albeit with different approaches. Yang et al. [104,105] both used designs that involved the reading of moralised and non-moralised statements and found that moral disgust content was processed before that of physical disgust, in the latter case, evidencing this by greater P300–400 responses. Luo et al.'s [103] findings seem to contrast with this; they ascribed an earlier EPN to physical disgust rather than moral disgust, suggesting the opposite pattern observed in the Yang papers. The main difference between designs for these contrasting results is in the task, i.e., full statements vs single words. This may have the biggest impact on processing times as it is possible a greater number of systems must be recruited to ascribe meaning to moralised words rather than a full statement [114]. A similar pattern to Luo's is found in Zhang et al. [106], who found images eliciting physical disgust produce earlier ERPs than those eliciting moral disgust. This can also be explained by more necessary neural recruitment to ascribe meaning to the moral images rather than the obviously disgusting physical images, which also likely produce a threat response, necessitating the early recognition of this content. The findings for EEG/ERP designs, then, are mixed, but it is important to consider the type of design being used. Where less obvious physically disgusting and potentially threatening content is readily visible or forthcoming, it may be that moral content is processed sooner; however, this appears to be the reverse where physically disgusting content is more pronounced.

In the tDCS/lesion studies, areas identified in the fMRI studies reviewed earlier are identified in these papers too. In Ciaramelli et al. [115], the ventromedial pre-frontal cortex (vmPFC), associated with emotion regulation [116], and connected to various other structures associated with disgust and moral processing, is found to be closely linked to interpersonal, but not moral disgust. The usual caveats apply here with regards to methodology (specifically socio-moral vs. bodily-moral violations); however, this may help distinguish physical and moral disgust, at least with regards to the engagement of the vmPFC. When targeting the insula with tDCS [107,112], it was found that anodal stimulation of the T3 region (e.g., insulae) increased reported disgust, disgust word completion, and increased HRV were observed in response to statements based on the MFT (excluding care). The reverse pattern was observed when cathodal stimulation was applied instead. Finally, Vicario et al. [108] demonstrated reduced distaste-related MEPs in response to TMS of the tM1 site whilst viewing moralised vignettes, an effect which did not occur in a control site (hM1, hand), suggestive of an evolutionary disgust response. Whilst difficult to summarise these different approaches together, it is possible to see, for the most part, connections between the physical disgust response and that of the moral disgust response, when theoretically shared neural structures are either damaged or stimulated. Whilst, as with the previous fMRI section, this does not provide (nor need to) evidence of a central seat of moral disgust processing, it does highlight again how there is a clear overlap between the structures involved in both physical and moral disgust processing.

Finally, from a behavioural perspective, it appears that moral disgust again shares hallmarks of a physical disgust response, as well as having characteristics which distinguish it from this. The two types of disgust are, in Chan et al. [109], potentially very alike, as moralised scenarios in three conditions appear to lead to reduced consumption of foodstuffs, typical of an aversive distaste response. The two are found to be less alike in Żelaźniewicz et al. [111], where hand-grip strength is assumed to be an indicator of physical fitness, and therefore should be negatively correlated with disgust sensitivity. Such a trend was found for physical and sexual disgust, but not for moral disgust, and generally, this may be more indicative of a reduced need to protect the physical envelope in moral disgust; however, this is at odds with a purity definition of moral disgust. Lastly, Franchin et al. [110] used a FACS system to differentiate facial expressions in response to moralised transcripts and found that anger was the most highly reported and recognised emotion in response to all moral foundations. These papers are again difficult to summarise together; however, they help to highlight how there may or may not be a stark difference between what someone is actually experiencing or processing, and how this is outwardly manifested. These manifestations of physical and moral disgust change in each of the above methodologies, and this is a useful reminder that stringent control of methodology is necessary if hoping to target purely the disgust aspect of "moral disgust".

5. Comparing moral disgust responses to physical disgust

This review has essentially sought to complete and combine two separate reviews, hoping to determine the common physiological, neurological, and behavioural markers of both physical and moral disgust. This section will now compare the findings of each subheading for physical and moral disgust, using evidence wherein contrasts can be made between the two disgust types will be evaluated in this section.

5.1. Physiological markers of moral and physical disgust

5.1.1. EMG/facial expression studies

As physical and moral disgust are theoretically closely related, it is not surprising that the methodologies reviewed in these sections targeted similar facial muscles for EMG and facial expression analysis. Both physical and moral papers targeted at least the levator labii [59,68,92], whilst others also included the corrugator supercilii [30,61,66,72,90,93,94,98], and some designs including both these and the zygomaticus major [28,95] or also even the medial frontalis in addition [91]. With regards to levator labii activity, this was generally increased across the board in the studies cited previously, with one exception; Buchtel et al. did not observe this increase in individuals from Hong Kong. Of those including the corrugator supercilii, mixed findings are reported, with de Jong et al. [66] and van Overveld et al. [72] observing decreased or no corrugator supercilii activity, respectively, in response to physical disgust. For moral disgust, Whitton et al. [30] observed greater

corrugator supercilii activation for disgust and anger induction, though other moral papers [28,91,94,98] noted increased corrugator supercilii activation only in response to anger induction.

However, some moral papers also found no corrugator supercilii activation at all [90,93,95]. As no physical disgust papers examined the zygomaticus major or medial frontalis, it is not possible to draw empirical comparisons between disgust types here, though as these muscles are associated with happiness and surprise, respectively [91], they may not be prioritised as sites of interest, at least in geographically western samples. For the reviewed papers here, it can be concluded that physical and moral disgust generally share activation of the levator labii, whereas anger is not characterised in this way. For research purposes, the distinction between levator labii and corrugator supercilii activation could be a useful marker to determine which emotion an individual is processing, and if this matches with the intended target emotion.

5.1.2. Physiological measures

Interestingly, it appears that even within one type of disgust, there are different physiological markers of disgust processing. In physical disgust, the subcategories of core disgust and animal-reminder have been found to reduce heart rate [62,64,67,69,70], or increase heart rate [66,68,74], respectively, and it is posited in this review that this depends on visible contamination vs. identifiable threat or harm. This helps to explain similar findings in moral disgust, where more bodily-moral violations are associated with reduced heart rate [96,98] or increased HRV [107,112], and socio-moral, or angering, stimuli by increased HR [96,98]. Only Ottaviani et al. [97] found findings converse to the disgust response previously, and this is perhaps due to the stimuli instead eliciting anger rather than the targeted moral disgust.

Generally, it appears both physical disgust (core only) and moral (purity) disgust share similar cardiological responses, most likely due to the fact that these are more likely to include scenarios where contamination of the body-envelope is possible. Animal-reminder disgust, which includes injury and harm, elicits similar responses to socio-moral violations, perhaps due to the depiction of similar scenarios, which in turn are more likely to elicit anger and thereby explain the differential effects on HR/HRV.

When considering galvanic skin responses (GSRs) between disgust types, it appears at least in physical disgust that an increased GSR response is homogenous [66,67,70,72], and this is less pronounced than other negative experiences such as pain [62], although it can be hard to separate from other threatening emotions or even pleasant emotions [65]. Rubenking and Lang [98], however, found reduced GSR responses to stimuli with bodily products, but increased GSR activity to body envelope stimuli. The latter may represent a difference between pure physical disgust and moral disgust, though Sharvit et al. [101] found increased GSR activity in response to disgusting stimuli associated with moralised statements. Whilst Sharvit et al. don't necessarily elicit moral disgust here, the only other moral disgust papers monitoring GSR [90,93] found no significant differences in activity, making it difficult to draw conclusions here. Ultimately, it appears strong emotional responses might elicit a GSR increase, and without further investigation into these responses with regard to moral disgust, GSR responses might only be useful as an indication that reported emotions are being processed by an individual, and used as a measure of overall arousal.

The other observed measures, such as saliva production [66,72] and salivary immune markers [71], body temperature [67,71], and gastric activity [74], are again not explored in the moral domain of disgust in the papers reviewed, so contrasts are difficult to make here.

5.2. Neurological markers of moral and physical disgust

As tDCS/TMS/lesion studies were not reviewed as a focus in the physical disgust review, parallels between the disgust types cannot be commented on here. The summary in the moral disgust section covers this, and the remaining neurological categories between disgust types are contrasted below:

5.2.1. fMRI studies

Both types of disgust share common areas of activation, with the insula being commonly recruited when processing physically disgusting [73–75,77,87,99] and morally disgusting stimuli [25,49,100–102]. There appear to be distinctions between specific insula regions activated depending on disgust type. Core disgust, and purity-related moral disgust stimuli, appear to more commonly activate the AI [77,87,99–101], and the PI appears more activated in animal-reminder and socio-moral disgust subtypes, or interpersonal disgust [49,102].

A common conclusion drawn by these papers is that the insula is not the only structure recruited in disgust processing. Physical and moral disgust both appear to result in activation in frontal areas [25,49,75,77,99,100], possibly an indication of both disgust types' goal-driven action tendency [117]. Some areas such as the OFC may also give clues as to how the information is processed, with disgusting areas recruiting smell and taste-oriented structures [118], or may just have to do with the type of task used to elicit the target emotion, for example, vignettes in Oaten et al. [99] activating the IFG, associated with language processing [119].

The other key finding highlighted in the reviewed papers appears to be the distinction between ACC and PCC activation dependent on disgust type. The PCC has been commonly attributed to moral cognition, and the thought processes of others [100], and Sharvit et al. [101] demonstrate that this activity may be dependent on personal experience of moral transgressions, rather than the act itself. This makes sense due to the PCC's increased connectivity to the hippocampus [120] and so may become more highly activated when memory retrieval is necessary to contextualise a transgression, similar to as is seen in Schaich Borg et al. [49]. The ACC, however, whilst similarly attributed to social judgement, appears to be less dependent on personal contextualisation, with a possible explanation being that in disgust processing, more immediate cues, such as threat recognition (including contamination), drive their contextualisation instead. This is supported by findings in physical [73] and moral disgust [100,102] where the disgusting aspect has been either core or bodily-moral. Furthermore, this was also observed in Parkinson et al., when harm violations were experienced, which further supports the notion of a readily accessible emotional response not dependent on experiences of the self, but also highlights how this pattern may manifest in emotions other than disgust.

Overall, it appears that both disgust types share commonly activated neural structures in their processing, and despite some apparent differences between them, these differences can also include the closely related emotion of anger. Therefore, this further highlights the importance of ensuring that the targeted disgust type is being hit, rather than a blend of the two, or something else entirely.

5.2.2. EEG/ERP studies

It is difficult to draw parallels based on these types of design alone in this review, due to the fact that the physical disgust section only had one paper with this as a focus. Indeed, using ERP studies alone to comment on the processing of different types of emotion may not be sufficient (as with any measure); however, the papers here can be useful in elucidating observations from other sections.

Krusemark and Li [79] found in physical disgust that, despite disgust and fear both being identified as threatening, disgust appears to be processed more slowly than fear, seemingly with a suppression of this processing evident, suggestive of an avoidant response. Unfortunately, the remaining papers included in the review don't compare disgust processing times with those of fear, so further exploration of this threat-avoidant response can't be discussed here. However, what is apparent is the earlier processing times of moral content when eliciting

disgust using vignettes/statements [104,105], and contrastingly later processing times when using single words [103], or images [106]. As discussed previously, this may well be to do with how apparent the disgusting content is (i.e., do images and single words require less judgment), and may help to explain differences in activation of, for example, the ACC and PCC highlighted in the previous section.

5.3. Behavioural studies

The behavioural papers in this study suggest somewhat mixed findings between disgust types. From a purely physically disgusting standpoint, the usual avoidant action tendency tends to be supported in Nord et al.'s [89] example of reduced oculomotor avoidance of disgusting stimuli following anti-emetic treatment. Similarly, Chan et al. [109] find that reduced consumption behaviours in response to morally disgusting scenarios, perhaps indicating that moralised disgust also results in reduced gastronomic activity, or at least reduces appetite. This is somewhat supported by Żelaźniewicz et al. [111], in which differences between physical disgust and moral disgust are identified, although not from an avoidant response, but of physical fitness (and therefore readiness for the body to combat contaminants), something not observed in moral scenarios. In this way, it is possible that physical disgust requires an avoidant response and increased physical resilience, or at least behavioural markers relying on these factors may be more obvious for physical over moral disgust. Finally, it appears that facial expressions as a behavioural marker of disgust processing might not be entirely reliable, as Franchin et al. [110] found increased anger expressions in response to purity violations, a finding at odds with those from the EMG sections in each review. Altogether, whilst difficult to summarise four very different methodologies here, we tend to see a pattern of avoidance which is characteristic of physical disgust repeated in moral disgust, at the very least when it comes to appetite. It would be useful in the future for moral disgust studies to include clear conditions comparing physical and moral disgust, to further explore the similarities, and if this avoidance is observed in behaviours unrelated to consumption or appetite.

6. General discussion

This review has sought to determine what the literature around physical and moral disgust suggests their typical markers following targeted elicitation are. From the previous summary, it is possible to see that physiological responses generally align across the two disgust types, with facial muscle movements, cardiological activity, and galvanic skin responses exhibiting similar results across disgust modalities and methodologies. There are instances where findings are divergent from the majority of other research in their respective sections, though it's possible that, due to theoretical and methodological limitations, something akin to moral outrage (a blend of disgust and anger), may have been the true response. Other methodological caveats are addressed in more detail in their respective review sections; however, the confusion between the theoretically morally disgusting purity violations and other, angering moral foundation violations tends to be a possibility for contrasting findings. A similar pattern to this is found in the neurological studies reviewed, although comparisons here are more difficult and somewhat less useful to make. The reason for this is that whilst common areas of disgust processing are, of course, of interest when comparing disgust types, it is less significant to observe, for instance, that moral disgust activates areas that physical disgust doesn't. A finding such as this might only highlight that different neural regions are recruited when ascribing meaning to a moral violation, and so not observing this in physical disgust might not be surprising. Despite this, it could be a useful marker that the "moral disgust" being targeted is indeed moralised, and not instead only physically disgusting. Additionally, contrasts between moral disgust and moral anger are useful here, as in Oaten et al. [99]; however, the sample size of papers in this review that make this contrast purposefully is not enough to draw clear conclusions and is something that should be addressed in future methodologies. Finally, we see a general pattern of avoidance in both disgust types, which is consistent with theories and evolutionary models of the behavioural action tendency expected with physical disgust.

It is useful here to highlight studies where only physical disgust or moral disgust are being closely compared, and this requires that they meet a criterion. Based on previous theoretical models seeking to discern moral disgust and anger [121], and empirical research which has supported such theories [19], it is suggested here that the most useful comparisons between physical disgust and moral disgust are those between core-disgust (physical), and bodily-moral/purity violations (moral). These disgust types are the most closely aligned, whereas animal-reminder (physical) and socio-moral violations (moral) are suggested to be closely related, given the overlap of harm/care content in the former. There are relatively few cases where studies reviewed here have controlled for this specifically, though many moral papers do include violations which could fall into the purity foundation and others in one of the other four. This also highlights the importance of the caveats provided in the introduction of this review, whereby the use of purity violations to target moral disgust might be flawed. As Gray et al. [122] suggest, there might well be differences in the perceived severity of different kinds of moral violations, which requires further investigation.

There are also additional confounders beyond the reliance on purity violations. For instance, in Buchtel et al. [91] and Cannon et al. [28], the actor behind the violation is clearly identified as, or the violation as happening to, someone else, however in Ritter et al., [94], and Ottaviani et al. [107], the vignettes frame the participant as directly experiencing or engaging in the moral violation. This brings into question differences between affective and semantic valence [123], in which individuals reporting experienced disgust might be reporting semantic emotions in the former (how they know they should feel), and affective valence in the latter case (how they actually feel). As Chakroff et al. [124] show, moral violations involving others are often judged to be more wrong than those including the self, and when they do include the self, it is the person and not the action which is shown to be more wrong. In addition to this, impure actors were found more morally wrong than the act itself, whereas the converse was found in harmful acts. By signifying increased moral condemnation of harmful acts, perhaps semantic valence is targeted rather than affective valence. In a similar vein, Giner-Sorolla et al.'s [51] suggestion that moral disgust might be a social signal to aid with remaining within social groups may help to explain this differentiation – a "bad character". If a person is judged to be impure, this can be used as a signal to others that they wish to distance themselves from the individual, rather than engaging in an explanation of an immoral behaviour which might have occurred only once. Whilst this may be more relevant for moral disgust rather than physical disgust, it is useful to point out how the social signal of distancing oneself from a bad character to aid survival in a social group resonates with evolutionary ideas of avoiding physical contamination.

Another main characteristic of the papers contained here is that intentionality of the acts is not always closely controlled for. Generally, intentional violations are used in methodologies (e.g., [28,30,93]), however, some designs reviewed here also include accidental, or potentially unavoidable violations [96,99] or those which are more focused on ethical dilemmas rather than more defined violations of specific foundations [108]. Not controlling for intention could influence responses to moral violations, as Parkinson & Byrne (2018) point out that intentional violations are judged as more severe than unintentional violations. As the specific intention of moral violations in some studies reviewed here is not controlled for, it makes it difficult to fully understand what effect this has on the intensity of processed emotions as

measured by physiological or neurological signals. Interestingly, Young and Saxe [125] and Chakroff et al. [126] suggest that intention matters only for harmful violations, and not purity violations. Contrastingly, Kupfer et al. [127], and Kollareth and Russell [128] suggest that intention does contribute to perceived severity of purity violations, at least as much as it does for harmful violations. Kollareth and Russell investigated this by disambiguating statements to be pernicious, benign, or unspecified with the same outcomes, but the effect of this with an accompanying image hasn't been fully investigated. The only paper in this review that includes both text and image was Bakker et al.'s [90] study of political in/out-groups, so as to make the intention or moral transgressions of the person depicted to be made clear, but this addition of contextualisation and disambiguation hasn't been widely applied to methodologies. With this in mind, when comparing responses, it is crucial to ensure all moral violations are committed with the same intention behind them, although this paradigm still requires further exploration. Interestingly, whilst intention might be more relevant for morally disgusting violations, it is worth considering that in designs which aim to target physical disgust, if an actor in a scenario intentionally interacts with something physically disgusting, this might inherently become a morally disgusting violation. An example of where this might be the case is in de Jong et al. [66]; however, there are many more instances where this encroachment from physical into moral disgust appears. Using this example to illustrate, whilst vomit is physically disgusting, the act of eating so many eggs and drinking so much milk, you purposefully vomit might also be considered a moral violation.

Taken together, it is not surprising that there are significant overlaps in physiological and behavioural responses between physical and moral disgust. As outlined, it is important that the "disgust" aspect of moral disgust is targeted to make effective comparisons between moral and physical disgust, which potentially necessitates the use of purity violations, although the challenges presented by defining the purity construct must be addressed. Furthermore, it is important to understand if the act itself or the actor is the source of moral disgust, as this may help to elucidate why an individual condemns a moralised scenario, either because it is inherently physically or morally disgusting, or because they wish to signal they are not associated with the transgressor. Finally, intention needs to be closely controlled for, as this might directly contribute to condemnation, but extra care needs to be taken in defining what is moralised and what is not (i.e., only physically disgusting) when including intentional violations.

6.1. *Future considerations*

With purity violations and core-disgust elicitors being so similar, or even a requirement of moral "disgust", then, aside from the metaphorical use of the term, does the emotion itself exist? Whilst increased disgust has often been reported in response to purity violations, it is difficult to conclude that this is the elicitation of moral disgust, and not merely the elicitation of disgust, plus a contamination of moral condemnation misidentified as disgust.

Future research, therefore, needs to determine, when using closely controlled purity violations, if intention does indeed contribute to increased levels of condemnation, but also experienced disgust, and this is not only the case for harmful violations. Once this paradigm has been further investigated, it would then be prudent to develop a methodology which includes socio-moral violations to compare how reported levels of condemnation and disgust contrast between different moral foundations. Based on Landmann and Hess [19], it is expected that disgust would be much higher for purity violations, and anger for all socio-moral violations. However, as Chapman and Anderson [50] suggest, it can be very difficult to fully disentangle these two moralised emotions. Therefore, by using methodologies which use more than one of the types of measures included in this review, it might be possible to determine if emotional processing induced by exposure to morally vs. physically disgusting scenarios matches the reported level of condemnation or emotion. In doing so, further investigation of semantic vs. affective valence, as well as moral outrage as a social signal, is possible.

An additional consideration for future research is to review papers which specifically investigate the neurophysiological markers for the domain of sexual disgust, as its exclusion from this review may limit the interpretation of the literature. Some papers reviewed here contain sexual content (e.g., [49,63]), but this is often blended into sub-categories of disgust outlined in the general discussion. More recent research has also found that sexual disgust often arises from violations which fit comfortably into these sub-categories [129] and may involve a degree of self-disgust which is not captured by much of the methodology in the literature reviewed here [130]. A review of sexual disgust would therefore represent an important contribution to the literature, provided that other- vs. self-directed disgust is considered, and that the studies reviewed successfully isolate sexual disgust from physical and moral disgust, an issue which has proven difficult for studies seeking to elicit the latter two domains within this review.

7. Conclusion

This systematic literature review has aimed to determine, beyond self-report, what methodologies have been utilised to elicit and measure physical and moral disgust. It is possible to see significant overlap between these two emotions, although they often also exhibit distinctive patterns of response. Furthermore, experienced disgust might also be dependent on the type of physical or moral elicitor used, with the findings of this review suggesting that core-disgust and bodily-moral/purity violations are likely to elicit physical disgust, and animal-reminder and socio-moral violations might elicit a blend of anger, disgust, and even fear. Due to this potential for overlap, it is imperative that future research scrutinises methods of elicitation closely in order to better understand what type of disgust is being elicited. Perhaps, just as physical disgust might have evolved to protect us from physical contamination, moral disgust serves a similar purpose of protecting us against social opprobrium, though the mechanisms and motivations behind this might differ depending on the violation being committed.

This begins a discussion about lexical confusion, and what we truly mean when we say someone's behaviour is morally disgusting. If moral disgust is a social signal to others to indicate a desire to distance from a transgressor, then this might involve situations which might usually result in anger. This paradigm needs more investigation to determine if anger responses can eventually become replaced by disgust, and the use of physiological measures is suggested here to help further elucidate this.

In the meantime, this review has found that the "disgust" aspect of moral disgust is likely due to the presence of physically disgusting cues, often referred to in purity violations. Given the previous discussion here, future research will need to determine if purity violations contribute more to disgust over other types of violations, if this is the case for both core and animal-reminder physical disgust, and if these responses are influenced by the type of purity violation and the intention of the transgressor.

CRediT authorship contribution statement

Oliver Hawkins: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonia Ypsilanti:** Writing – review & editing, Supervision, Methodology, Data curation. **Petra Examilioti:** Data curation.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.physbeh.2025.115172.

Appendices

Appendix A. – List of EBSCO databases used

4. (Moral*) AND Disgust AND (Physiolog* OR Physiology OR emg OR electromyography OR brain OR neural* OR neuro* OR muscle OR facial OR heart* OR transgression* OR skin* OR gut*)

http://search.ebscohost.com/login.aspx?direct=true&db=aft&db=bri&db=buh&db=fgh&db=ccm&db=cax&db=i3h&db=nlebk&db=eax&db=20h&db=eric&db=f3h&db=ffh&db=8gh&db=30h&db=hjh&db=lxh&db=cmedm&db=kah&db=mzh&db=bwh&db=s3h&db=trh&bquery=(Moral*)+AND+Disgust+AND+(Physiolog*+OR+Physiology+OR+emg+OR+electromyography+OR+brain+OR+neural*+OR+neuro*+OR+muscle+OR+facial+OR+heart*+OR+transgression*+OR+skin*+OR+gut*)&cli0=RV&clv0=Y&type=1&searchMode=Standard&site=ehost-live

Database	Limiters Applied
Art Full Text (H.W. Wilson)	Scholarly (Peer Reviewed) Journals
British Education Index	Scholarly (Peer Reviewed) Journals
Business Source Premier	Scholarly (Peer Reviewed) Journals
Child Development & Adolescent Studies	Scholarly (Peer Reviewed) Journals
CINAHL Complete	Scholarly (Peer Reviewed) Journals
Communication Abstracts	Scholarly (Peer Reviewed) Journals
Criminal Justice Abstracts with Full Text	Scholarly (Peer Reviewed) Journals
eBook Collection (EBSCOhost)	Scholarly (Peer Reviewed) Journals
Education Abstracts (H.W. Wilson)	Scholarly (Peer Reviewed) Journals
Educational Administration Abstracts	Scholarly (Peer Reviewed) Journals
ERIC	Scholarly (Peer Reviewed) Journals
Film & Television Literature Index with Full Text	Scholarly (Peer Reviewed) Journals
FSTA - Food Science and Technology Abstracts	Scholarly (Peer Reviewed) Journals
GreenFILE	Scholarly (Peer Reviewed) Journals
Historical Abstracts with Full Text	Scholarly (Peer Reviewed) Journals
Hospitality & Tourism Complete	Scholarly (Peer Reviewed) Journals
Library, Information Science & Technology Abstracts	Scholarly (Peer Reviewed) Journals
MEDLINE	Scholarly (Peer Reviewed) Journals
MLA Directory of Periodicals	Scholarly (Peer Reviewed) Journals
MLA International Bibliography	Scholarly (Peer Reviewed) Journals
Regional Business News	Scholarly (Peer Reviewed) Journals
SPORTDiscus with Full Text	Scholarly (Peer Reviewed) Journals
Teacher Reference Center	Scholarly (Peer Reviewed) Journals

Appendix B. – Search terms

The physical disgust search term was as follows:

"(Physical disgust OR core disgust) AND (Physiolog* OR Physiology OR emg OR electromyography OR brain OR neural* OR neuro* OR muscle OR facial OR heart* OR transgression* OR skin* OR gut*)".

The moral disgust search term was as follows:

"(Moral*) AND Disgust AND (Physiolog* OR Physiology OR emg OR electromyography OR brain OR neural* OR neuro* OR muscle OR facial OR heart* OR transgression* OR skin* OR gut*)".

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