The Aggressive Body. Understanding Aggression Combining Virtual Reality, Computational Movement Features, and Neuroimaging

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Abstract

Among the many kinds of bodily expressions of emotion, anger occupies an important place because of its role in social interactions and aggressive confrontations that may threaten survival. We already have a basic understanding of how aggressive body expressions are perceived and how adaptive reactions are prepared in situations of social threat. But so far, most research has been conducted in laboratory settings with limited ecological validity. This review advocates the use of virtual reality in combination with other measurement techniques in order to better understand aggressive behaviors. Furthermore, a novel framework for the study of body expression is put forward which zooms into the detailed

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C. Martin et al. (eds.), *Handbook of Anger, Aggression, and Violence*,
https://doi.org/10.1007/978-3-030-98711-4_99-1

processes related to posture and movement features that sustain high-level semantic descriptions of aggressive behavior in daily interactions.

Keywords

Aggression · Body expression · Computational body features · Domestic violence · Embodiment · Emotion · fMRI · Social behavior · Threat · Virtual reality

Abbreviations

1PP	First-person perspective
3PP	Third-person perspective
ASD	Autism spectrum disorder
BEAST	Bodily Expressive Action Stimulus Test
DMN	Default Mode Network
fMRI	Functional magnetic resonance imaging
TMS	Transcranial magnetic stimulation
VR	Virtual reality

Social and Emotional Signals: Standing Up for the Body

Traditional emotion theories focus predominantly only on the perception of emotions from the face and tend to neglect the body. For example, the neural basis of anger perception has been investigated mainly by presenting pictures of angry facial expressions (Dawel et al. 2022). Yet, there is no doubt that faces and bodies are equally important in daily life and often convey information about identity, emotion, and gender along similar lines (de Gelder 2009). Notwithstanding earlier skepticism (Ekman 1965), emotions from visual body signals are as effectively recognized as those conveyed by facial expressions, as shown in various validation studies. For example, recognition of angry, fearful, and happy facial emotions was at 74.3% for the NimStim facial expression set (Tottenham et al. 2009), while the body postures in the Bodily Expressive Action Stimulus Test (BEAST) set were correctly recognized with an accuracy of 92.5% (de Gelder and Van den Stock 2011). Still, there are some important differences in the signaling functions of faces and bodies. Whole-body expressions of emotion, unlike facial expressions, do not simply consist of purely emotional expressions but show a person while performing an action. In contrast with facial expressions, bodily expressions tend to provide direct information about the action the agent is undertaking. For this reason, aggressive or threatening body postures tend to represent a more direct threat to physical harm than facial expressions (de Gelder et al. 2010).

Among the many categories of bodily expressions, anger occupies a special place because of its role in regulating social interactions and modulating aggressive confrontations in human (Argyle 1988) and nonhuman primates (Emery and Amaral 2000). The mechanisms whereby signs of aggression and reactions of fear are perceived at the level of the whole body and reacted to are now investigated extensively. A large body of research conducted in our laboratory over the last 15 years includes the behavioral and neural basis of these body expressions (de Gelder 2006; de Gelder and Poyo Solanas 2021, 2022), the interaction with facial information when it is consistent or not with the body expression (Meeren et al. 2005; Poyo Solanas et al. 2018), the influence of the real-world context on how the body expressions are perceived (Kret and de Gelder 2013), and last but not least, the influence of observers' personality profiles, such as the tendency for aggressiveness (Kret and de Gelder 2013), empathy (Van den Stock et al. 2015), or social anxiety (Kret and de Gelder 2013).

This research has made it clear that body expressions of anger and fear do not necessarily evoke the same response even though each can be viewed as a threat signal. For example, while similar activations have been observed for both angry and fearful dynamic bodies in temporal and prefrontal areas as well as in the amygdala, angry bodies also activated other regions in the anterior temporal, premotor, ventromedial prefrontal, and orbitofrontal cortices (Pichon et al. 2009). These findings are consistent with the notion that body expressions of anger signal a more direct threat than fearful body expressions and thus require more direct adaptive reactions from the observer. Indeed, a fearful body expression may be triggered by something perceived in the surroundings and when observers see this fearful expression it alerts them of a potential danger in the environment, whereas angry expressions provide an unequivocal threat signal for the observer. Interestingly, differences between these two sides of threat also seem to hold true when processed non-consciously, as angry body expressions tend to escape from suppression faster than fearful and neutral bodies as shown with continuous flash suppression paradigms (Poyo Solanas et al. 2022; Zhan et al. 2015).

Other studies have investigated gender differences in the processing of threatening body postures. For example, Kret et al. (2011) reported higher activity in motor preparation areas in men than in women when observing male versus female threatening body expressions. Researchers have also investigated anger, aggression, and fear expressions in daily interactions between two people or even in a group. In an fMRI study, Sinke et al. (2010) measured the brain correlates of observing an interaction seen as either teasing or threatening. Interestingly, the observers were very good at telling apart these subtly different situations, and different brain correlates were found depending on the observation of a teasing or a threatening exchange (Sinke et al. 2010). At a group level, studies comparing how brain processes differ when observing an interacting crowd expressing fear versus perceiving a similar group of people reacting individually and independently with panic, showed that there is increased anticipatory and action preparation activity in the interactive crowd conditions (Huis in 't Veld and de Gelder 2015).

Previous research has also shown the importance of correctly recognizing emotional expressions for normal social functioning. Examples of clinical populations with deficits in emotional recognition are autism spectrum disorder (ASD) (Hadjikhani et al. 2009) and schizophrenia (Van den Stock et al. 2011). Facial expression recognition deficits have also been reported in aggressive offenders

(Gery et al. 2009; Hoaken et al. 2007; McCowan et al. 1986; Sato et al. 2009) and psychopaths (Marsh and Blair 2008). Similar findings have been reported for the recognition of body postures. For instance, anger recognition and attentional biases toward anger are enhanced in violent criminal male offenders (Kret and de Gelder 2013). Kret and de Gelder (2013) found that imprisoned male offenders perceive body expressions differently than do controls. They were more distracted during a matching task by an image showing an angry posture and more often misjudged fearful body movements as expressing anger. When asked to categorize facial expressions while ignoring a simultaneously presented congruent or incongruent body posture, imprisoned male offenders performed worse than the control group. This was clearest when a smile was shown in combination with an aggressive posture. Concerning scene context effects, the impact of congruency between a violent scene and an angry body expression was highest for the violent offenders group. Consistent with this, violent offenders were comparatively impaired in recognizing a happy posture when viewed against the background of a violent scene. The results of these studies indicate the existence of specific biases in the perception of aggressive body language in violent behavior populations.

In line with a long tradition of emotion research, the studies just mentioned tended to optimize experimental control with sometimes unfortunate consequences for ecological validity. Often, the need for realistic social experiments like the above is difficult to combine with the requirements of methodology. Fortunately, advances in highly ecological techniques such as virtual reality (VR) (Monti and Aglioti 2018; Parsons et al. 2017), in combination with other measuring techniques (e.g., neuro-imaging, physiological measures, motion tracking, etc.), now makes it feasible to investigate aggressive behaviors in a more naturalistic manner. In the following sub-section, this phenomenon is explained in more detail through the discussion of studies where VR is used in combination with neuroimaging techniques to advance knowledge on aggressive behaviors, with a special focus on domestic violence.

Virtual Reality and Neuroimaging Techniques to Address Domestic Violence

One of the greatest potentials of studying aggressive behaviors through virtual reality is that it enables to simulate social situations with high ecological validity under fully controlled laboratory conditions (Sanchez-Vives and Slater 2005). In fact, VR allows researchers to study context-dependent behaviors in immersive virtual environments where participants typically experience perceptual illusions related to presence (i.e., feeling that oneself is really inside the virtual scenario) and plausibility (i.e., feeling that what it is occurring inside the VR is actually happening) (Slater 2009). As de Gelder et al. (2018) discusses, even if participants clearly distinguish the virtual nature of the VR simulations with respect to experiential reality, in most cases, they still experience a strong "suspension of disbelief" which leads them to behave as they would do in the real world (de Gelder et al. 2018). This has the additional advantage that during the experience of these vivid

VR scenarios, some emotional systems in the brain might run free from strict cognitive supervision due to the virtual nature of the simulations and the suspension of disbelief.

VR-based studies may also better deal with several ethical concerns related to exposing participants to any real danger or harm when researching violent behaviors. For instance, immersive VR scenarios have been used to carry out a virtual reprise of the controversial Stanley Milgram's obedience experiment (Slater et al. 2006), finding that participants report high levels of subjective distress and physiological reactivity when hearing, seeing, or delivering electrical shocks to a virtual character, analogous to the results obtained in the original experiment. Similarly, life-size immersive VR experiences have also been designed to study under what conditions bystanders intervene in order to try to stop a violent attack to a victim, showing that sharing a common social identity with the virtual victim (i.e., supporting the same soccer team) increases the probability of executing an intervention to protect the victim (Rovira et al. 2009; Slater et al. 2013). In this regard, Renaud et al. (2013) also used VR to depict different virtual characters in order to assess child molesters' and sexually non-deviant subjects' sexual preferences and intentional dynamics, something that would be impossible and completely unethical to perform in reality.

Finally, VR not only affords a better understanding of how individuals with different violent backgrounds and criminological profiles react to a specific virtual simulation, but it also allows to study how individuals react to that situation when experiencing it from the perspective of another person, for instance the victim's perspective (Seinfeld et al. 2018). Several studies have shown that individuals can experience strong illusions of body ownership toward a life-size virtual body given that a first-person perspective (1PP) of the artificial body and congruent multisensory feedback are provided (Maselli and Slater 2013; Seinfeld et al. 2021a). This is analogous to the rubber hand illusion where individuals report a strong feeling that a rubber hand is part of their own real body, when their real hand is hidden from their view, and instead they see a rubber hand in an anatomically plausible position being stroked at the same time and position where they are feeling touch in their real hidden hand (Botvinick and Cohen 1998). Such bodily illusions are presumably based on multisensory processing in the brain, with regions such as the ventral premotor cortex, intraparietal sulcus, primary somatosensory cortex, and temporoparietal cortex playing an important role (Blanke 2012; de Borst et al. 2020). Interestingly, studies have also shown that the type of body in which embodiment occurs can shape our perceptions, attitudes, and behaviors (Maister et al. 2015), and this knowledge has been leveraged to tackle real social problems such as racial bias (Peck et al. 2013) or domestic violence (Seinfeld et al. 2018).

Focusing on domestic violence, a series of studies have assessed some behavioral and neural correlates of embodying individuals who display aggressive behaviors in the perspective of the victims. In the study by Seinfeld et al. (2018), males with a history of intimate partner violence perpetration and a control group of non-offenders experienced the 1PP of a virtual female victim of domestic violence in VR. Through the use of a head-mounted display, male participants saw that their real body was substituted with that of a life-size female avatar (Seinfeld et al. 2018).

Moreover, the use of additional body tracking technologies also enabled participants to control the movements of the virtual body based on their own real-time body movements, therefore establishing agency and visuo-motor synchrony between the real and artificial body (Kokkinara et al. 2015). From the virtual female victim's perspective, participants experienced the verbal assault of a male avatar. At some point in the scene, the male character also performed an act of physical violence by throwing a telephone to the floor and at the end of the scene the virtual male offender was very close to the participants embodied as the female avatar, even invading their personal space. Before and after the VR scene, the emotion recognition abilities of the offenders and non-offenders were measured. The results revealed that before the virtual experience, offenders had a deficit in recognizing fearful female faces in comparison to controls, a factor which has been demonstrated to be positively associated with the occurrence of intimate partner violence (Marshall and Holtzworth-Munroe 2010). Another finding was that offenders display a bias toward classifying fearful faces as happy in comparison to non-offenders. The results indicated that the VR intervention based on embodiment in a victim's perspective enhanced offenders' sensitivity to recognize fear in female faces, reduced their bias toward classifying fearful faces as happy, and helped offenders identify with victims of domestic violence. Through this study, it was demonstrated that using immersive VR to change the visual perspective of an aggressive population may modify socio-perceptual processes thought to underlie this specific form of aggressive behaviors possibly by improving emotional recognition. Interestingly, this type of embodied perspective-taking experiences has also been recently used to enhance empathy for children who witness violent aggressions (Seinfeld et al. 2022), as well as for the treatments of perpetrators inprison (Barnes et al. 2022). A review focused on the use of VR for the prevention and rehabilitation of intimate partner violence can be found in Johnston et al. (in press).

A timely question concerns the underlying brain mechanisms of the behavioral effects observed in different VR studies related to aggressive behaviors and to embodying a victims' perspective. To disentangle these types of questions, recent studies have combined VR experiences with fMRI techniques, as for instance de Borst et al. (2020). In this study, fMRI measurements were gathered while participants either embodied a female victim perspective from a 1PP perspective or when experiencing the same situation from a third-person perspective (3PP). The findings showed that when threats are perceived as being directed to oneself (i.e., 1PP), in comparison to another person (i.e., 3PP), there is enhanced synchronization of fronto-parietal brain networks and amygdala activity across participants (de Borst et al. 2020). Moreover, body ownership and self-identification with the victim was higher in 1PP in comparison to 3PP, in accordance with some results obtained by Gonzalez-Liencres et al. (2020). These results illustrate the importance of brain areas that encode aspects of the bodily self and its surrounding space, as well as emotions in threat perception, mainly when the threat is directed toward one's own body.

In another study, Seinfeld et al. (2021b) focused on investigating what are the brain mechanisms implicated in the emotion recognition enhancements observed after embodying a domestic violence victim perspective in VR. In this case, participants underwent two fMRI scanning sessions, one before and after experiencing the same VR scene as the one used in Seinfeld et al. (2018). During each fMRI scanning session, participants passively observed emotional morphs of facial and bodily stimuli. The findings of this study suggest that the Default Mode Network (DMN) seems to play a critical role in the emotion recognition changes observed in previous studies, since DMN activity increased when processing ambiguous emotional expressions after the VR scene, however it decreased for clearly fearful expressions (Seinfeld et al. 2021b).

New Directions for the Study of Body Perception: Discovering Midlevel Features That Sustain Rapid Body Expression Perception and Applications

The examples discussed in the previous section show the potential of using VR in combination with MRI techniques to further advance our understanding of violent behaviors while overcoming ethical implications or the impossibility of replicating certain social aspects in the physical world (i.e., having the visual perspective of someone else). In addition, the combination of VR with neuroimaging techniques might play a fundamental role in understanding the mechanisms that support emotion perception by providing the ideal setup for the investigation of the critical midlevel features that characterize, for example, violent behaviors. Midlevel features refer to stimuli properties that drive perception at processing stages between low-level (e.g., edges, spatial frequency, motion direction) (Giese and Poggio 2003) and high-order semantic representations (i.e., high-level semantic categories of emotions, actions, and intentions) (Grill-Spector and Weiner 2014) while still carrying emotional information (de Gelder and Poyo Solanas 2021, 2022). In the case of body expressions, it refers to postural and kinematic properties such as the orientation of the head, the degree of limb contraction, or the overall movement velocity (de Gelder and Poyo Solanas 2021, 2022). For facial expressions, midlevel features refer to, for example, the distance and position of several facial landmarks (Alugupally et al. 2011).

One of the promises of a feature-based approach is its usefulness for the design of VR scenarios. Ever since the debate on the “uncanny valley,” the goal has been to make avatars and VR environments as realistic as technologically feasible. Although VR environments cannot and do not need to be fully realistic, it is of great importance that virtual avatars display the critical features that characterize a kind of behavior, such as, for example, an anger expression. In this regard, some important features of aggressive expressions have already been identified. For instance, angry and fearful body expressions are often characterized by a high degree of elbow flexion in comparison to other emotional expressions (Coulson 2004; Poyo Solanas et al. 2020b; Wallbott 1998). Although these two sides of violent interactions may indeed share some features, they also differ in others. For example, fear and angry body expressions are different with regard to the degree of body openness or the overall amount of body movement, both lower in fearful expressions (Coulson 2004; De Meijer 1989; Poyo Solanas et al. 2020b; Roether et al. 2009; Wallbott 1998). Yet, the most recognizable distinction between fearful and angry behaviors is the directionality of the movement (Poyo Solanas et al. 2020b), with fearful bodies associated with backward movement while angry bodies with approaching behavior (Carver and Harmon-Jones 2009; Harmon-Jones 2003). In this regard, submissive behavior is generally associated with a contracted body, a head inclined toward the chest, and a backward body movement (Carney et al. 2005) while dominant behavior with a flexed posture, a head inclined toward the back, and a forward body movement (Carney et al. 2005; Vacharkulksemsuk et al. 2016). In addition to the features characteristic of a person's behavior, recent research has also investigated interaction features. For example, more synchrony can be observed between the movements of two or more people agreeing whereas their movements become more asynchronous during an argument (Paxton and Dale 2017; Tschacher et al. 2014). Also, the perception of proximity can change depending on the appraisal of the interaction scene (Brennan and Martin 2012). Therefore, ensuring a good representation of the specific core features of the behavior under study will enhance the ecological validity of VR experiments.

Another important methodological promise of a feature-based approach is that the critical features related to violent behavior can be varied parametrically to measure the impact in behavioral and brain processes. VR provides the perfect tool for such approach because of the relative flexibility in the design of environments as well as avatar behaviors. In a study without VR, a step in this direction was taken by Roether et al. (2009), who identified critical emotion-specific features from gait by analyzing and varying postural and movement information and relating it to observer's judgments (Roether et al. 2009). The authors found that gait speed, among other dynamic features, strongly influenced the perception of emotion (Roether et al. 2009). Moreover, a feature approach in combination with both VR and neuroimaging techniques will provide new insights into social behaviors. For instance, it may help pinpoint the specific body features critical for the recognition of a range of social behaviors in normal controls as well as to understand how those features are being processed in clinical populations displaying emotional deficits. In this regard, it may also add to our understanding of the mechanisms behind the emotion recognition enhancements (Seinfeld et al. 2018, 2021b) and the changes observed at a brain network level (Seinfeld et al. 2021b) after embodying a victim of domestic violence or other types of aggressive behaviors in a VR scenario (Fig. 1). An example of the relation between features and brain activity comes from the study by Poyo Solanas et al. (2020b). Interestingly, the authors found that limb contraction, a body feature that clearly differentiated fear from other affective body movements, was encoded in several areas known for their involvement in body expression processing (Poyo Solanas et al. 2020a), especially fearful ones (de Gelder 2006; Meeren et al. 2016). These findings provide a more detailed explanation of the role of these areas in

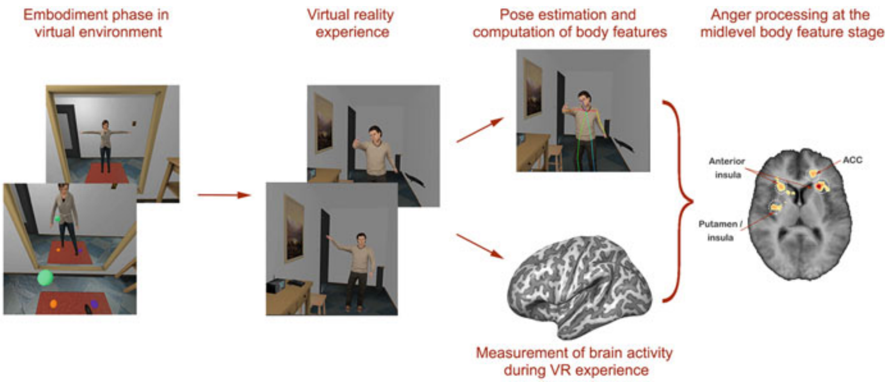

Fig. 1 Feature-based approach in combination with virtual reality for the study of anger processing. After the embodiment phase, participants immerse themselves in the virtual scenario while brain activity is being recorded. A computational approach to body feature definition allows then to find where in the brain-specific body posture and movement characteristics are being encoded. (Original images of the VR scenes were extracted from Seinfeld et al. (2018))

emotional perception than the categorical approaches used so far (de Gelder and Poyo Solanas 2021, 2022).

Taken together, a feature-based approach will have a crucial impact on our understanding of affect and social interactions, and may help identify central mid-level features in relation to social perception problems. This may, in turn, open a door for new treatment possibilities (de Gelder and Poyo Solanas 2021, 2022). For example, the identification of critical features associated with emotional recognition deficits in violent offenders (Marsh and Blair 2008; Seinfeld et al. 2018) and the application of this knowledge to programs focused on their rehabilitation (Barnes et al. 2022) may improve treatment efficacy. Furthermore, the brain areas or networks responsible for emotional recognition deficits in violent offenders can also serve as targets for noninvasive treatment procedures, such as transcranial magnetic stimulation (TMS) or neurofeedback. In this regard, TMS has shown to successfully improve symptoms of depression (George et al. 2000), anxiety (Cirillo et al. 2019), and Parkinson's disease (Brys et al. 2016) as well as being useful in the treatment of aggressive behavior (Volpe et al. 2022). These new feature-based treatment opportunities could also extend to other clinical populations suffering from disorders of affective communication, such as autism spectrum disorder and schizophrenia. Interestingly, several accounts have suggested that affective deficits in ASD may be rooted in abnormal biological movement perception (Blake et al. 2003; Hadjikhani et al. 2009). Moreover, a feature-based approach will not only provide new treatment opportunities, but may also help in the deployment of security assistance in situations involving aggressive behaviors. For example, the automatic recognition of features that characterize violent interactions by surveillance systems may help deploy quick assistance to victims or prevent the escalation of a situation.

Yet, a feature-based approach in the study of violent behaviors, as well as other body expressions, comes with challenges. An obvious difficulty in investigating affective body perception is the fact that body postures and movements are complex and high-dimensional (Roether et al. 2009). There are currently several approaches for the identification of critical features of basic natural actions and emotional behaviors, adding to more traditional behavioral descriptions. In recent years, computational models have proposed a solution to the multidimensionality problem as well as to the subjective feature selection in observational studies. Yet, a continuous challenge for many current computational approaches is to reckon with the neurophysiological properties of the visual system (Giese and Poggio 2003; Hasson et al. 2020). To bring closer the biological reality of the brain and computational models, it has been proposed that the discovery of biologically plausible relevant midlevel features should be adhered to a neuroethological framework (Anderson and Perona 2014). This entails input from powerful ethology-inspired methodologies that can describe and quantify the natural behavior under natural circumstances (Anderson and Adolphs 2014; Anderson and Perona 2014). This is what the combination of virtual reality, neuroimaging techniques, and computational feature approaches can contribute.

Applications of the Material

This chapter reviews previous work on the behavioral and neural basis of aggressive behaviors and proposes to use virtual reality as well as a midlevel body feature analysis for a more ecological understanding of the neurobiology of aggressive behavior.

Mini-Dictionary of Terms

- ***Autism spectrum disorder (ASD)***: range of neurological and developmental conditions that normally impair normal social interaction and communication.
- ***Functional magnetic resonance imaging (fMRI):*** non-invasive method that localizes brain activity with excellent spatial resolution by detecting fluctuations associated with blood oxygenation and flow.
- ***Neurofeedback***: non-invasive treatment method based on self-regulation training in response to real-time feedback about brain processes.
- ***Midlevel body features***: analysis of body posture and movement characteristics at a (computational, neural) level that is beyond physical features (low-level) and not capitalizing on everyday semantic categories (high level).
- ***Transcranial magnetic stimulation (TMS)***: non-invasive technique used to enhance or inhibit neural activity in a specific area of the brain by means of a strong local magnetic field.
- ***Virtual reality (VR)***: computer-generated environment that allows a person to interact with virtual objects, scenes or avatars in an immersive manner.

Key Facts

Key Facts of Aggressive Body Behavior

- Aggression is reliably communicated by the face but also by specific body postures and movements.
- Aggressive behavior is often characterized by body features such as a high degree of elbow flexion or a forward movement in comparison to other emotional expressions.
- Intimate partner violence perpetrators have a deficit in recognizing fearful female facial expressions and also display a bias toward classifying fearful faces as happy in comparison to non-offenders.
- The identification of critical features associated with emotional recognition deficits in violent offenders and the application of this knowledge to programs focused on their rehabilitation may improve treatment efficacy.
- VR interventions based on embodiment in a victim's perspective has proven to improve the recognition of female fearful expressions as well as to decrease biases in emotional perception, an effect which seems to be mediated by changes in the Default Mode Network (DMN).

Summary Points

- Appropriate recognition and reaction to angry body expressions is essential for normal social functioning and interaction.
- Virtual reality in combination with neuroimaging techniques constitute a highly ecologically valid technique for the investigation of aggressive and other social behaviors.
- Embodiment may become a powerful tool for behavioral change.
- Virtual reality constitutes a promising tool for the treatment of emotional recognition deficits and other maladaptive social behaviors.
- A midlevel body feature framework promises a better understanding of the processes underlying social perception by looking into the detailed processes that sustain high-level semantic processing (Fig. 1).

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