Análise Psicológica (2026), 44 (2): e2269 doi: 10.14417/ap.2269

General

Selective corrugator activity indexes embodied processes during decisions about when to act

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Abstract: The temporal lead of electromyographic activity relative to overt movement suggests that these signals can capture decisional processes of when to act. Drawing on the feelings-as-information theory, we examined whether individuals' momentary affective experiences shape their behavioral decisions through the activation of facial muscles typically associated with affective states (zygomatic and corrugator). Twenty-four participants completed a hand-adjustment task in a dynamic environment that required precise coordination between hand movements and a continuously changing space. Active perceptual-motor adaptation in this task was compared with a purely observational condition. Results showed selective increases in corrugator activity during behavioral decision-making only when participants were actively performing the task. Moreover, corrugator activation built up progressively and was time-locked to action initiation. No significant modulation of zygomatic activity was observed. Taken together, these findings are not fully consistent with simple valence-based explanations and suggest that the corrugator may index a broader embodied state associated with readiness to act. We conclude that facial electromyography is a useful tool for detecting subtle preparatory processes and that affective experiences may be one of several information factors guiding motor behavior.

Keywords: Feelings-as-information, Action decisions, Action-selection, Embodied cognition, Facial electromyography.

Introduction

Embodiment theories argue that the perceptual, sensorimotor and affective systems are constitutive components of cognition rather than downstream consequences of mental processing (e.g., Barsalou, 2008; Clark 1999; Proffitt, 2006; Wilson & Golonka, 2013). If we accept this embodied perspective, it follows logically that interoception, the perception of the body's internal physiological states (such as heartbeat, breathing, hunger, temperature, and visceral sensations), must be an integral part of cognition. The evidence supporting this claim further shows that conscious awareness is not required for internal bodily information to guide evaluative judgments (e.g., Pessoa, 2008; Winkielman et al., 2007).

The hypothesis that sensorial and experiential mechanisms inform cognition finds clear expression in several theoretical approaches. One example is the mood-as-information or feeling-as-information theory (Schwarz & Clore, 1983). This framework argues that affective and

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phenomenological states provide real-time cues that guide evaluations and behavior. Evidence consistently shows that participants evaluate events more negatively when experiencing negative mood than when experiencing positive mood (e.g., Clore, 1992; Schwarz & Clore, 1983, 2007). We also find the same assumption in the processual or perceptual fluency literature. For example, the experience of perceptual fluency is accompanied by positive affect, which in turn biases judgments in a positive direction (Garcia-Marques et al., 2010, 2016; Winkielman & Cacioppo, 2001).

Evidence on subjective experiences of mood and fluency is particularly relevant because these are subtle phenomenological states (i.e., feelings) with a clear links to internal bodily physiology (e.g., Barrett, 2006; Lindquist et al., 2016). Their influence therefore bears directly on theories positing that internal physiological signals play a crucial role in informing our decisions and actions. For instance, Damasio (1999) argued in his somatic marker hypothesis, that bodily signals arising from physiological changes, such as variations in heart rate, hormonal responses, or visceral sensations, serve as markers that guide reasoning and choice. The hypothesis entails that feelings arising from body-brain loops help select or bias a course of action rather than actions being determined by pure deliberative cognition alone. Similarly, Pessoa (2008) emphasizes that emotion and cognition are deeply integrated within the brain's architecture, such that cognitive processes are not independent of affective states but are shaped by them through dynamic, reciprocal interactions. According to this perspective, feelings have an important role in shaping our behaviour, supporting Zeelenberg et al.'s (2008) view that "feeling-is-for-doing". Moreover, it highlights that feelings are not mere by-products but active drivers of actions and choices. The general view is that feelings are likely to reflect the organism's internal physiological state and function as a continuous background that shapes perception, evaluation, and decision-making. This view assumes cognition not as a detached, purely rational process but one that is inherently embodied, with the body's internal physiological states providing essential information for adaptive thought and behaviour.

However, although evidence indicates that interoceptive and bodily feedback mechanisms (e.g., autonomic responses, insula/ACC activity) correlate with decision-making under uncertainty (for a review see Ohira, 2016), to our knowledge no study has directly linked the activation of an embodied response to a decision-making process involving action, specifically, decisions about when to act. The research most closely related to this question has primarily examined how bodily information is used to adapt and rescale physical measurements into action-relevant perceptual metrics (Franchak & Adolph, 2014; Linkenauger et al., 2013; see Andel et al., 2017, for a review). Classic demonstrations include the use of leg length to judge stair climbability (Warren, 1984) and evidence that pregnant women adjust judgments of passability through doorways in line with bodily changes across gestation (Franchak & Adolph, 2014). Manipulations of hand size, whether via prostheses (Ishak et al., 2008) or virtual body illusions (Linkenauger et al., 2013), similarly show that individuals rapidly recalibrate judgments of passability and graspability. Together, these findings demonstrate that dynamic bodily cues support moment-to-moment decisions about action possibilities but have not directly addressed the role of feelings as a mediator of such effects.

In this paper, we address the hypothesis that the activation of interoceptive, embodied responses, experienced as feelings, guides the decision-making process of when to act. Specifically, we investigate whether internal bodily cues contribute to such decisions by examining peripheral physiological activity measured through facial electromyography (fEMG). fEMG activity measures the electrical signals produced by facial muscle fibres during contraction and can be used as a potential marker of embodied cognitive processes (see Fridlund & Cacioppo, 1986). We approach this question by leveraging the fact that fEMG can detect subtle and often unconscious changes in muscular signals, allowing us to capture both the moment at which an individual commits to an action and the preparatory processes unfolding prior to that decision. In some studies of emotional expression, fEMG focuses on two key muscles: the *zygomaticus major* and the *corrugator supercilii*. The *zygomaticus major* is located on the cheek and is activated during positive affect, especially when smiling, and shows increased EMG activity in response to pleasant or rewarding stimuli (Tassinary et al, 2007). In contrast, the *corrugator supercilii*, situated above the eyebrows, contracts during frowning and has been associated with negative affect and aversive stimuli (Larsen et al., 2003). However, and importantly to our aims, research has shown that the corrugator activity may also reflect cognitive elaboration (Cacioppo et al., 1986; Petty et al., 1988). More broadly, *corrugator supercilii* activity has been associated with a range of experiences, including difficulty, and discomfort, as well as cognitive and physical activities such as increased focused attention (Matthews & Meck, 2016), mental exertion (Goodmurphy & Ovalle, 1999; Van Boxtel & Jessurun, 1993; Waterink & Van Boxtel, 1994), and physical effort (de Morree & Marcora, 2010, 2012). Previous research examining other muscle activity that are unrelated to affective experiences support our methodological decision. For instance, Bai et al. (2011), although not working with facial EMG, showed that voluntary wrist-extension movements can be predicted before overt movement onset by analysing online EEG in conjunction with non-facial EMG signals. Their findings highlight that peripheral muscle activation captured by EMG offers a reliable ground truth for action initiation, and that measurable preparatory activity precedes the onset. Similarly, Wentink et al. (2013) used non-facial EMG (in combination with kinematics) to detect that gait-initiation intention approximately 130-260 ms before toe-off in non-amputees. Their findings show that EMG changes occurring prior to movement onset can reliably signal upcoming action decisions (e.g., starting to walk).

Overview of the study

Here we test the empirical hypothesis that feelings indexed by fEMG activity signals the appropriate moment for action initiation. In this view, the fEMG pattern should reflect internal states (ex., effort, readiness, or affect) that guide the timing of action execution. We propose that such fEMG-derived signals can *inform when or whether* an action is initiated.

Building on research suggesting that bodily information is particularly relevant when an action is at stake (see above), we developed a ball-grabbing and hand-fitting experimental paradigm to examine whether such feelings emerge selectively during action execution. To distinguish feelings arising from mere perception of the elements of the task from those occurring during the execution of the action itself, we recorded participants' fEMG activity while they either performed a hand-fitting task or merely observed the task scenario without acting. Our analysis will focus on *zygomaticus major* and *corrugator supercilii* muscle activity. If momentary feelings inform action capabilities, we predict greater fEMG activation during the hand-fitting conditions compared to mere observation, particularly when action execution is possible. Differences in the activity of the two measured muscles will help clarify the affective nature of the subjective experience activated by the acting goal. In this regard, we further expect that if the alignment or match between the object's size and the hand elicits a positive affective experience, then *zygomaticus major* activity should increase at that moment relatively to the baseline (Cannon et al., 2010; Regenberg et al., 2012). Under these circumstances we do not expect informative changes in *corrugator supercilii* activity. Even considering the affective component of the phenomenological experience, if alignment is experienced as a relief from discomfort, then we should observe a significant decrease of corrugator activity compared to baseline signalling the easing of a negative state. However, if alignment mainly experienced as the fulfilment of task demands required an increased attentional focus, then we should observe increased activation of the corrugator as a "ground-truth" marker (e.g., Bai et al, 2011) of movement onset. In this case, a corrugator response should reflect attentional and motor preparation processes rather than the affective properties of the experience.

Experiment

Participants

Twenty-four native Portuguese-speaking students (23.83 ± 4.54 years; 11 males and 4 left-handed) were recruited from various universities in Lisbon. All of them received monetary compensation and provided written consent *prior* to the experiment. Participants had no history of attention disorder and had normal or corrected-to-normal vision. The *a priori* power analysis performed on G*Power for an ANOVA with a full within-subjects design with four condition (Observing *vs.* Fitting the hand x Events: reducing /expanding) and 11 time-window (-200 ms, -100 ms, RKM, 100 ms, 200 ms, 300 ms, 400 ms, 500 ms, 600 ms, 700 ms, 800 ms) with the standard correlation of 0.5 between the repeated measures targeting a sample size that would detect a small to medium effect ($\eta^2 = 0.04$ to 0.10). Research on corrugator supercilii EMG responses in both affective and non-affective paradigms with a power of 80% and alpha of 5% suggested a sample size between 12 to 20 participants (e.g., Berger et al., 2020; Bradley & Lang 2000; Lang et al., 1993; van Boxtel & Jessurun 1993) suggest that effects are typically small to moderate in magnitude.

Material and apparatus

Two events that produce information at the level of the optical flow (visual information created by movement on our retina) were selected for this experiment: the baseball shirking in size and the square expanding in size.

The ball video was created using a first reference image of a 3D baseball (150 pixels per inch and 252.5 pixels in diameter) centered on a black background (800 x 600 pixels). The initial image of the ball was reduced (10%) to create a new image. This process was repeated, with a 10% reduction from the previous image, until we reached a total of 20 images (Adobe Photoshop CC, Version 14.2 x 64). The visual stimuli were created to be displayed at different speeds, with each image presented for durations of either 20, 30, 40, 60, 70, or 80 ms. These visual stimuli were then compiled into six different video files (Windows Movie Maker, Version 2012, 16.4.3528.0331).

The construction of the square video had, as the first image, a 2D square with 150 pixels/inch of resolution and a distance between outlines equal to 472 pixels. The same steps used in the creation of the ball video were replicated.

The two videos, with their six different speeds and opposite movements, were pre-tested for both perceived threat, speed, and accuracy. Given that the approaching visual stimulus (i.e., looming effect) triggers threatening experiences (see also, Cléry et al., 2015; Vagnoni et al., 2012), we opted for the video that shows a baseball reducing in size (i.e., visual receding) and a square expanding/increasing in size (Figure 1). For each visual stimuli, we selected the speed of the videos that participants rated as fast (i.e., $M = 6.00$ on a 1 – very slow to 7 – very fast scale) but still manageable to execute (i.e., $M = 4.00$ on a 1 – very easy to 7 – very difficult scale). This speed corresponds to presenting each image for 40 ms, a duration that operationalizes the task as a constrained spatial-temporal task. Both videos were presented using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) on a 23-inch monitor (100 Hz) with a resolution of 800 × 600, against a black background at a distance of 50 cm from the participant. The released key moments were recorded with a PST Serial Response Box with 1.0 ms of precision.

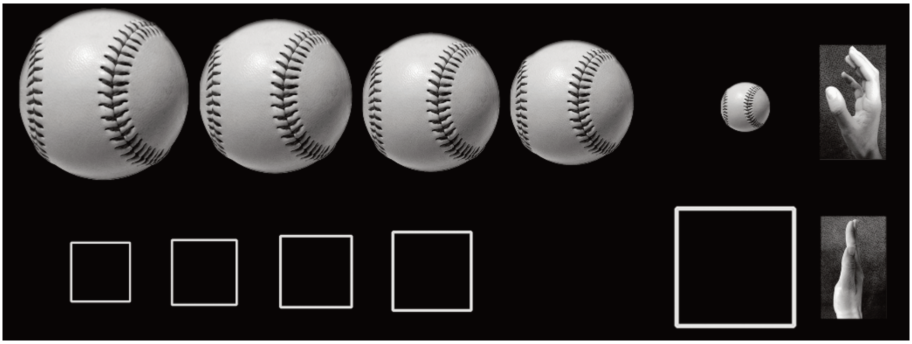

Figure 1. A sample of the sequence of the sizes used to create the dynamic events, and the respective action hand indicated for grasping the ball and fitting-through into the square space

fEMG recording. Electromyographic signals were collected using a Biopac MP100 system equipped with EMG100C amplifiers (Biopac Systems Inc., Goleta, CA). Both measures were amplified by a factor of 5,000 and sampled at 1,000 Hz frequency. Bipolar fEMG signals were recorded using electrode placements on the left *corrugator supercilii* and *zygomaticus major* muscles to decrease the interference by the motor response (using the right hand) (e.g., Cacioppo et al., 1986; Larsen et al., 2003; Tassinary et al., 2007). This practice is based on the typical symmetrical activation that indicates unlikely potential asymmetric correlations with different motor brain structures involved in perceptual judgment. Two 4-mm Ag/AgCl electrodes were placed along the muscle fibers over each site with 1.5 cm between electrode centers. The skin surface at these sites was cleansed and gently abraded before placing the electrodes. All *fEMG* signals were recorded with an online 10-Hz low-frequency cutoff filter and a 500-Hz high-frequency cutoff filter. The ground electrode for the EMG measures was placed in the left hand (i.e., skin conductance electrodes, in accordance with the Biopac guidelines).

Procedure

Participants arrived alone at the lab, and after signing the informed consent form were instructed to sit in front of a computer screen in an individual booth. The experimenter then took time to place the electrodes and explained to the participants that he/she would leave the room but return by the time the experiment finished. All further instructions were presented on the computer screen and covered the standardized position of the right hand for each trial condition. Two blocks of trials were performed by each participant, with the dynamic events counterbalanced within each block. In the first block (Observing condition), participants watched 10 trials of each dynamic event that unfolded on the screen while the participants kept both hands resting on their thighs. In the second block (Fitting hand condition), the same participants indicated when the size of the ball afforded to grasp for 15 trials and when the size of the square afforded passing one´s hand through the changing aperture for 15 trials. Specifically, the participants released a key pushed and held from the start of each trial to mimic the action of grabbing the ball or passing the hand through the available space. This release indicates when they feel that they were able to grasp the ball and fit through the square aperture. Each trial started with a fixation cross that varied randomly and equally between 2,000 ms and 2,200 ms and ended with a blank screen that remained on screen for 1,500 ms (inter-trial interval). The Observing condition always preceded the Fitting condition since performing the motor task beforehand could prime action-related mental processes, thereby influencing neural and behavioral responses in what was intended to be a purely observational condition.

fEMG data processing. In the fitting-hand condition, 6% of trials were missing because participants did not release the key. Among the remaining valid trials, an outlier analysis excluded 1.78% of trials, together with their corresponding *fEMG* recordings, because response times were more than three standard deviations above each participant's mean response time. *fEMG* activity from the *corrugator supercilii* and *zygomaticus major* was processed in AcqKnowledge 4.0 (Biopac Systems Inc., Goleta, CA). Signals were visually inspected for noise, artifacts, and anomalous waveforms, and were then filtered offline using a 20-400 Hz band-pass filter, with the 20 Hz high-pass component used to reduce blink-, eye movement-, and other low-frequency artifacts (Tassinary et al., 2007). A 50 Hz notch filter was additionally applied to reduce power-line interference. The filtered signals were rectified and smoothed using a 20 ms moving window. All preprocessing steps were conducted at the single-trial level prior to epoching and averaging. To control for baseline activity, a pre-stimulus baseline was calculated for each trial as the mean fEMG activity during the 500 ms preceding video onset. Trials with response errors, artifacts, or fEMG activation exceeding three times the participant's average standard deviation for each muscle within the interval from 500 ms before to 1600 ms after video onset were excluded. This procedure led to the exclusion of 9.13 ± 0.70 trials per participant in the observation condition and 12.63 ± 1.44 trials per participant in the fitting-hand condition. The rectified and smoothed signals were then averaged into 100 ms epochs over a time window extending from 1000 ms before stimulus onset to 5000 ms after stimulus onset. Finally, fEMG data were standardized within participants and muscle sites by transforming them to z-scores, thereby reducing the influence of highly reactive participants (Neta et al., 2009; Tassinary et al., 2007). Reported *fEMG* z-scores were expressed relative to baseline, such that values greater than 0 indicated activity above the pre-stimulus level. For the fitting-hand condition, the temporal window of interest was defined relative to the 100 ms epoch containing the key release, here termed the *release-key moment* (RKM). The final analysis window extended from 200 ms before the RKM to 800 ms after the RKM. The 200 ms pre-RKM interval was included to account for electromechanical delay effects (Cavanagh & Komi, 1979; Hug et al., 2011), whereas the 800 ms post-RKM interval was selected to allow sufficient time for *fEMG* responses, which may emerge with delays of approximately 300-400 ms after the relevant event (Dimberg & Pettersson, 2000; Dimberg et al., 2000). Because no key release was available in the observation condition, trials in that condition were aligned to an index computed as each participant's mean RKM in the fitting-hand condition (RKMa), and the same analysis window, from 200 ms before to 800 ms after RKMa, was extracted. This alignment assumes that a comparable evaluative process occurs in both conditions and that its timing in the observation condition can be approximated by the mean RKM from the fitting condition.

RKM statistical analysis. All analysis was conducted in SPSS. A first analysis approached only data from fitting hand condition and checked the possible effects over response time of non-planned factors such as gender, hand-laterality, and type of visual event. The average RKM supported a three-way mixed ANOVA with 2 genders (male/female) × 2 hand-preference (left/right) as between factors × 2 dynamic events (reducing /expanding) as within-factor.

fEMG statistical analysis. Data was analyzed within the relevant design factors: 2 tasks (Observing vs Fitting the hand) × 2 events (reducing /expanding) × 11 time-window (-200 ms, -100 ms, RKM, 100 ms, 200 ms, 300 ms, 400 ms, 500 ms, 600 ms, 700 ms, 800 ms) within a general linear model, with task, event and time-window as within-subject factors. The Greenhouse-Geisser correction for degrees of freedom was applied when Mauchly's Test indicated the violations of the sphericity. To directly assess differences in the temporal dynamics of corrugator activation across the two conditions, planned linear trend analyses were conducted separately for each condition. These analyses were designed to capture systematic changes over time, with the expectation that such effects would be most pronounced in the fitting-hand condition.

Results

RKM

Analysis revealed as significant the main effect of event F (1, 20) = 40.84, $p < .001$, $\eta^2 = 0.67$, indicating participants were faster when judging the hand-ball fitting window (M = 432.18, SD = 36.52) than when judging the hand- square fitting window (M = 620.39, SD = 31.56). No other main effects were found (all $F < 1$) ensuring that gender and hand dominance did not interfere with the results in this paper, we follow the convention of not reporting p values for $F < 1$ since it indicates that random within-group variability exceeds between-group differences, leaving no detectable signaland suggesting that $p = 1$. As such we drop this factor in subsequent analysis (excluding these participants from the analyses did not alter the overall pattern of results).

Corrugator supercilii fEMG

Results show a significant main effect of the task, F (1, 23) = 4.69; $p = .041$, $\eta^2 = 0.17$, suggesting that increased activity of the corrugator relative to each participant's baseline occurred more strongly in the fitting hand condition (M = 0.26, SD = 0.29), compared to the observing condition (M = 0.11, SD = 0.19). Moreover, pass-ability (M = 0.26, SD = 0.23) was greater than grasp-ability (M = 0.11, SD = 0.24), F (1, 23) = 5.341, $p = .030$, $\eta^2 = .19$. The activity of the corrugator changed significantly with time, F (3.278, 88.383) = 8.51, $p < .001$, $\eta^2 = .27$, and with no significant interaction with the type of task, F (3.278, 75.395) = 1.91, $p = .129$, $\eta^2 = .08$.

To directly test our hypothesis regarding the temporal dynamics of corrugator activation, we separately tested the linear trends in the observing and fitting tasks. The polynomial contrast analysis for the linear trends clarified that corrugator activity only increased over time in the fitting the hand condition, t (23) = 3.58, $p = .002$, $d = 1.50$, and not in the observing condition, t (23) = -1.49, $p = .151$, $d = .62$ (Figure 2).

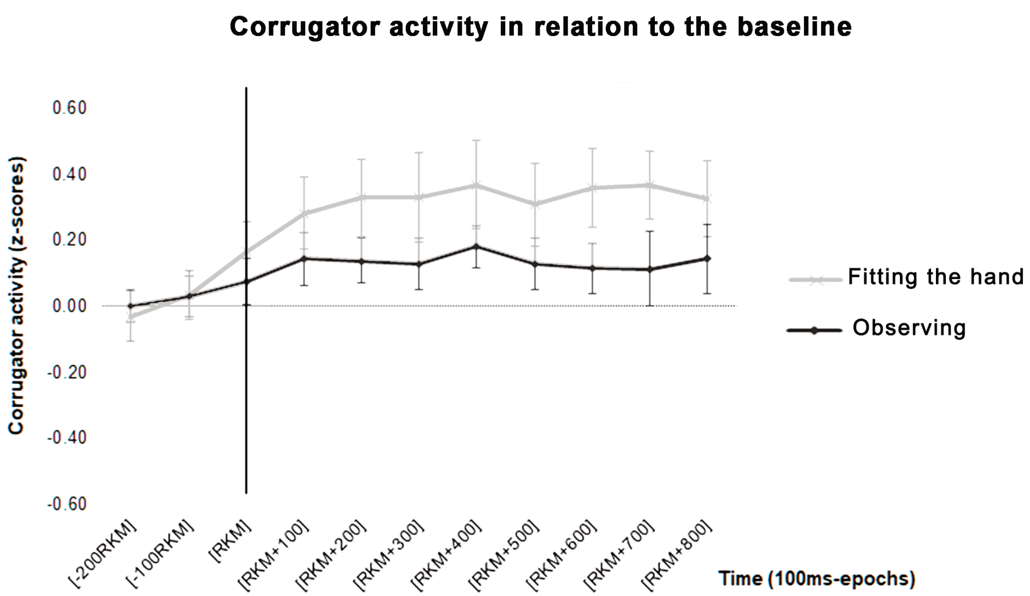

Figure 2. Electromyographic activation of the facial muscle corrugator concerning the baseline (before video onset) while observing vs. indicating the hand fitting moment

No interactions were found between the type of task and events ($F < 1$); between the events and time-window F (4.666, 107.316) = 1.29, p = .278; nor was second-order interaction found between task, events, and time-window F (5.130, 117.998) = 1.56; p = .176.

Zygomaticus major fEMG

No significant effects were found for the activation of the zygomatic muscle. No main effects of task ($F < 1$), event ($F < 1$), or time-window F (3.67, 84.41) = 1.46, p = .226.

Discussion

In this paper, we have investigated whether internal bodily cues, reflected by feelings, contribute to decisions about when to act by contrasting fEMG activity when an action is at stake compared to a purely observational context. Moreover, by monitoring the activity of the *zygomaticus major* and the *corrugator supercilii* muscles throughout the task, we were able to assess the role of embodied affective information in action decision-making. The first finding of this study is that hand-fitting and action-scaling decisions were associated with selective changes in *corrugator supercilii* activity, whereas no modulation of the *zygomaticus major* was detected. This suggests that the corrugator activity is likely to be the one supporting the decision process. Moreover, the effects on the corrugator consisted of an increase in activity that built up over the RKM period. This interpretation considers that corrugator activity begins at approximately -100 ms. Additionally, when the brain sends a motor command to the corrugator (facial) muscle, neuromuscular transmission and muscle fiber contraction require time, introducing a latency between neural activation and the measurable EMG signal (Cavanagh & Komi, 1979; Hug et al., 2011). This clearly indicates that the corrugator activation was linked to the specific context in which a decision about an action had to be executed. The observed temporal alignment of corrugator activation with the RKM, is highly likely to suggest that facial EMG can capture embodied evaluative and preparatory processes that inform decisions about when to act. Below, we discuss why these results are informative and relevant.

The exclusive involvement of the corrugator, in the absence of any modulation of the zygomatic, provides important insight into the mechanisms underlying the observed effects. Although some authors (e.g., Heller et al., 2014; Larsen et al., 2003) suggest that the corrugator activity maps negative valence changes in the subjective affective experience, which would suggest that deciding when to act was linked with the activation of a negative affective state, a substantial body of evidence points to a broader functional role. Specifically, increases in corrugator activation have been reported in tasks with high attentional demands (Van Boxtel & Jessurun, 1993; Waterink & Van Boxtel, 1994), sustained attentional focus (Matthews & Meck, 2016), as well as during mental exertion (Goodmurphy & Ovalle, 1999), and physical effort (de Morree & Marcora, 2010, 2012). Accordingly, an alternative interpretation of corrugator activation is that it reflects a phenomenal correlate of resource mobilization during task engagement, rather than negative valence alone. Importantly, the literature suggests that cognitive effort and attentional demands could be phenomenologically experienced as aversive which in the case of our experiment would blur the boundary between the affective states elicited by the task and the cognitive effort required to meet task demands (Inzlicht et al., 2018; Oliveira et al., 2023). We therefore consider it likely that the corrugator activity in the present experimental task indexed an integrated embodied signal reflecting readiness, effort, and evaluative processing associated with the decision of when to act, which may account for the observed effects. Nevertheless, the current experimental design does not allow us to rule out the presence of an affective component in this decision. In addition, because we did not directly measure attentional or effort-related demands in the observing and fitting conditions, we cannot exclude the possibility that these conditions differed in attentional, motor-preparatory, or effort-related requirements. We do not consider this possibility incompatible with our interpretation, as such demands are likely part of the broader embodied state engaged when an action decision is required and may therefore have contributed to the observed effects. Future studies should be specifically designed to disentangle the components likely reflected in corrugator activity and map their relative contributions, clarifying the extent to which corrugator activation during action decisions reflects action-decision processes, affective valence, task-related effort, resource mobilization, or a combination of these processes.

Our interpretation of the findings carries over to the results for the *zygomaticus major*. We expected to find an increase in zygomatic activity in the action context reflecting a positive affective experience associated with an alignment or match between the object size and the hand. Contrary to this prediction, we have not found any effect of the zygomatic between the experimental conditions or even throughout the task. Given that *zygomaticus major* activity is commonly associated with positive affect and reward-related processing (Larsen et al., 2003; Tassinary et al., 2007), the absence of modulation suggests that action initiation in this paradigm was not accompanied by an informative positive affective experience. The null effect for the *zygomaticus major* helps to argue against a simple valence-based account of the phenomenological state involved, which increases the plausibility of an explanation grounded in cognitive effort and task engagement as drivers of corrugator modulation. However, it should be noted that zygomatic responses could be context dependent and harder to find when the tasks do not have overtly affective stimuli (Cacioppo et al., 1986; Dimberg et al., 2000; Larsen et al., 2003), as such we do not see our results as conclusive about the hypothetical role of valence of feelings in the decision to act process.

Finally, the temporal dynamics of fEMG reported in the present study highlights the utility of fEMG as a tool for investigating the embodied mechanisms underlying action decisions, since it allows the detection of subtle and often unconscious physiological changes over time that preceded overt action. For this analysis, it is important to consider that although the increase in activation before the RKM is small, the peak corrugator activity occurs approximately at the time of the RKM. Given the expected delay in EMG recordings of facial muscles, this pattern suggests that the underlying neural activation is likely to align with the RKM. The temporal alignment of corrugator activation with the RKM suggests that fEMG can capture embodied evaluative and preparatory processes that inform decisions about when to act. In this regard, it extends previous findings reporting that peripheral muscle activity can predict movement onset prior to overt execution (Bai et al., 2011; Wentink et al., 2013) and studies showing that bodily information is continuously used to calibrate action possibilities (Fajen, 2005; Franchak & Adolph, 2014; Linkenauger et al., 2013).

A potential caveat of our study is that, although we pretested all materials to ensure that threat was not a factor induced by the experimental setting, we cannot entirely rule out its possible influence. This is important because corrugator supercilii activity has been shown to increase in response to threat-related manipulations, including risk of punishment (Lindström et al., 2013), fear conditioning paradigms, and anticipatory threat contexts, supporting its role as an index of defensive or avoidance-related responding. The visual looming effect induced by the expanding square – reflecting retinal expansion – has been argued to convey threatening information (Cléry et al., 2015; Schiff et al., 1962; Vagnoni et al., 2012) and may therefore account for the main effect observed in that condition. Nevertheless, our main results were not qualified by the stimulus material, suggesting that the RKM-related increase in activity was present even under those conditions. Future studies should further investigate the role of perceived threat, particularly given that physiological activation can be psychologically interpreted as threat depending on contextual cues (Dutton & Aron, 1974; Schachter & Singer, 1962; Tomaka et al., 1997).

In conclusion, in our view the study results are consistent with an embodied view of cognition in which internal physiological states can function as integral components of action decision-making and provide functional information to determine when an action should be initiated. The selective increase in corrugator activity in the action condition is not fully explained by a purely affective valence-based account of the underlying mechanism and opens questions to future research regarding when and under what conditions valence may play a role in the action decision process. Future studies manipulating affective valence and task demands independently will be crucial for further disentangling the affective and effort-related contributions to corrugator activity in action contexts.

Declaration of conflicting of interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

All procedures applied in this study was approved by the ISPA – Instituto Universitário Ethics Review Board and performed in compliance with the principles of the Declaration of Helsinki. All the collected measures, manipulations, and exclusions are reported in this paper.

Funding

This work is funded with national funds from FCT – Fundação para a Ciência e Tecnologia, I.P., in the context of the project UID/04810/2025 – William James Center for Research.

Authors contribution

Conceptualization: CF, GAO, TGM; Methodology: CF, AF, TGM; Formal analysis: CF, TGM; Writing – Original draft: CF, TGM; Writing – Review and editing: GAO, TGM.

All the authors read and approved the final manuscript.

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Atividade seletiva do corrugador indexa processos corporizados em decisões sobre quando agir

Resumo: A precedência temporal da atividade eletromiográfica em relação ao movimento explicito sugere que estes sinais podem capturar processos decisionais de quando agir. Com base na teoria de sentimentos como informação, investigámos se as experiências afetivas momentâneas moldam as decisões comportamentais através da ativação de músculos faciais tipicamente associados a estados afetivos (zigomático e corrugador). Vinte e quatro participantes realizaram uma tarefa de ajuste manual num ambiente dinâmico que exigia coordenação precisa entre os movimentos da mão e um espaço em constante mudança. A adaptação percetiva-motora ativa nesta tarefa foi comparada com uma condição puramente observacional. Os resultados mostraram aumentos seletivos na atividade do corrugador durante a tomada de decisão apenas quando os participantes estavam ativamente a realizar a tarefa. Além disso, a ativação do corrugador aumentou progressivamente e esteve temporalmente alinhada com o início da ação. Não foi observada qualquer modulação significativa da atividade do zigomático. Em conjunto, estes resultados desafiam explicações simples baseadas na valência e sugerem que o corrugador pode indexar um sinal corporizado de prontidão para agir. Concluímos que a eletromiografia facial é uma ferramenta útil para detetar processos preparatórios subtis e que as experiências afetivas podem ter um papel informativo na orientação do comportamento motor.

Palavras-chave: Sentimentos-como-informação, Decisão de ação, Seleção de ação, Cognição corporizada, Eletromiografia facial.

Submitted: 26/12/2025 *Accepted:* 04/05/2026 *Published:* 16/09/2026