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Biological postural oscillations during facial expression of pain in virtual characters modulate early and late ERP components associated with empathy: A pilot study

Thomas Treal [a,b], Philip L. Jackson [c,d,e], Aurore Meugnot [a,b,*]

[a] *Université Paris-Saclay CIAMS, 91405, Orsay, France*
[b] *CIAMS, Université d'Orléans, 45067, Orléans, France*
[c] *École de Psychologie, Université Laval, Québec, Canada*
[d] *Centre Interdisciplinaire de Recherche en Réadaptation et Intégration Sociale (CIRRIS), Québec, Canada*
[e] *CERVO Research Center, Québec, Canada*

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ABSTRACT

There is a surge in the use of virtual characters in cognitive sciences. However, their behavioural realism remains to be perfected in order to trigger more spontaneous and socially expected reactions in users. It was recently shown that biological postural oscillations (idle motion) were a key ingredient to enhance the empathic response to its facial pain expression. The objective of this study was to examine, using electroencephalography, whether idle motion would modulate the neural response associated with empathy when viewing a pain-expressing virtual character. Twenty healthy young adults were shown video clips of a virtual character displaying a facial expression of pain while its body was either static (*Still condition*) or animated with pre-recorded human postural oscillations (*Idle condition*). Participants rated the virtual human's facial expression of pain as significantly more intense in the *Idle condition* compared to the *Still condition*. Both the early (N2–N3) and the late (rLPP) event-related potentials (ERPs) associated with distinct dimensions of empathy, affective resonance and perspective-taking, respectively, were greater in the *Idle condition* compared to the *Still condition*. These findings confirm the potential of idle motion to increase empathy for pain expressed by virtual characters. They are discussed in line with contemporary empathy models in relation to human-machine interactions.

1. Introduction

Empathy, which is defined as the ability to share and understand the mental states of others [1], has been widely studied in affective and social neurosciences [1–5]. Although different theoretical models have been proposed to describe its underlying processes, scholars in neuroscience agree that empathy involves at least two core processes: (1) a mostly automatic emotional sharing of other people's states, called affective resonance, which allows an individual to represent what the other person might feel based on one's own, similar, affective experiences, and (2) a more controlled cognitive process, called perspective-taking (or mentalising), which refers to explicit reasoning about others' mental states [1,5–8].

Electroencephalography (EEG) is a neurophysiological technique that monitors electrical brain activity during an event, such as the

* Corresponding author. Faculté des sciences du sport de l'Université Paris Sud, Bât. 335 rue Pierre de Coubertin, 91405 Orsay France.
E-mail address: aurore.meugnot@universite-paris-saclay.fr (A. Meugnot).

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completion of a task or the presentation of a stimulus (e.g., image, video or sound). One common analysis, called event-related potential (ERP), involves analysing the electrophysiological response, i.e., changes or 'waves' in the electrical signal reflecting the neural changes associated with this specific event. An ERP is usually described according to its polarity (negative [N] or positive [P]), its latency from the presentation of the event, typically expressed in milliseconds (e.g., 300), and its location on the scalp based on standardized frames of reference [9,10]. In pain empathy EEG literature, studies using an ERP analysis suggested a dissociation in timing between affective resonance and perspective-taking [11–13]. In a seminal study, Fan & Han [12] recorded ERP to pictures of hands in painful situations compared to hands in neutral situations. Hand pictures elicited early negative ERP components (i.e. with a negative polarity) measuring between 110 and 300 ms (N110 or N200) which were greater in the painful condition, and their magnitude was correlated with self-unpleasant feeling. The authors proposed that this early differentiation between painful and neutral stimuli reflects affective resonance when seeing someone in pain. By contrast, a greater amplitude for the painful situations in later evoked potentials, occurring between 360 and 800 ms (P3 or LPP), were associated with the cognitive evaluation of other's pain, namely the mechanism of perspective-taking. These ERP findings have been reproduced multiple times (e.g., Refs. [11,13–16]; see Ref. [17] for a meta-analysis and some limitations), supporting the original proposal of Fan & Han [12] regarding the temporal dynamic features of pain empathy processes.

'Classical' stimuli of pictures depicting injured limbs (e.g. Refs. [12,14], or facial expressions of pain (e.g., 2012 [13,14,18–20]) have led to great advances in the understanding of human empathy. Now, however, there is a need for more ecological paradigms, namely to create experimental setups that reproduce the complexity and fluidity of empathic interactions in a controlled manner [5,21,22]. Thus, virtual reality appears to be a powerful tool in the domain of social cognition as it preserves the rigorous control and constraints imposed by experiments while simulating a natural interaction [21,23–26]. In particular, more and more paradigms using expressive computer-generated characters (virtual humans) have been developed [27,28].

Despite expressing enthusiasm for virtual human stimuli, scientists acknowledge their limits: virtual representations of humans cannot be perceived with the same familiarity as real humans, even when they are highly realistic [24,28,29]. Evidence shows that this perceptual divergence also impacts neural processing, as certain differences in brain activations associated with emotion perception are observed when comparing virtual characters and humans [12,30–34]. For instance, in Fan & Han [12], the authors compared the neural responses evoked by pictures of human hands with those evoked by cartoons of these hand pictures. Unlike the hand stimuli, the cartoons elicited no significant different response between the painful and neutral stimuli for the N200 component, suggesting that the cartoons failed to trigger an early automatic affective resonance. This interpretation was corroborated by the lack of correlation between the ERP amplitudes evoked by painful cartoons and the scores of self-unpleasantness. Overall, these findings offer compelling evidence that the reaction toward an emotion expressed by a virtual character may be partially artificial (i.e., a lack of emotional resonance towards its facial expression). So, the genuineness of the facial expression of virtual characters needs to be enhanced in order to provoke a more spontaneous affective reaction in individuals who interact with them.

One way to achieve this goal is to consider a fundamental characteristic of human beings, that is, we are constantly moving, even very slightly [35]. Thus, one way to enhance the anthropomorphism of virtual characters would be to infuse them with idle motion. This motion refers to all movements that are permanently present in humans, such as postural oscillations, breathing or blinking [36]. Recent studies by our group have demonstrated the potential of idle body animation to enhance the perceived intensity and believability of facial expressions of pain in a virtual human [37], as well as self-reported empathic response towards its facial expressions of pain [38]. Using a within-subject design, the objective of this study was to extend these previous findings using EEG to investigate how the presence of idle motion affects the neural processing associated with both affective and cognitive components of empathy when viewing a virtual character animated with a facial expression of pain. Based on previous studies [12,32], it was hypothesised that idle motion would modulate specifically the early ERPs associated with affective resonance (P2 and N2–N3 fronto-central [12,13,17]), while no significant difference between the *Idle* and *Still conditions* would be observed for the later component associated with perspective-taking (LPP central-parietal [12,13,17] and right central-parietal [39]).

2. Method

2.1. Participants

Twenty young adults who reported no neurological or psychiatric disorder took part in the experiment (7 women, mean age = 23.1 ± 3.8 years, range = 18–29 years). The sample size was based on previous studies with a similar design [12–14,40,41]. Each participant had normal or corrected-to-normal vision. The study was approved by the Ethics Committee of Paris-Saclay University (#CER-Paris-Saclay-2020-147) and conducted in accordance with the Declaration of Helsinki. Participants gave written informed consent to take part in this study.

2.2. EEG recording

EEG activity was recorded continuously from 64 active electrodes (actiCAP slim, Brain Products GmbH, Gilching, Germany) at a frequency of 5000 Hz with acquisition reference at FCz. Electrode impedances were kept under 50 kΩ. Blinking was detected using an electrooculogram (EOG) (two electrodes placed above and below the left eye) and Fp1 and Fp2 electrodes.

2.3. Stimuli

The stimuli consisted of two video clips (duration = 1 s) showing the upper body of a virtual young white adult male character from the Empathy-Enhancing Virtual Evolving Environment (EEVEE) [21]. The video clips were created using Blender® (Blender Foundation, Amsterdam, Netherlands). The virtual character was animated with a dynamic facial expression of pain, either with body animation (*Idle condition*, see the *Body Animation* section below for a detailed description of the method) or without body animation (*Still condition*).

2.3.1. Animation of facial expression of pain

The character's facial expression of pain was created using Action Units (AUs) according to the Facial Action Coding System (FACS) [42]. The characteristic AUs from the facial expression of pain [AU4 (brow lowerer), AU6 (cheek raiser), AU7 (lid tightener), AU9 (nose wrinkler), AU10 (upper lip raiser) and AU43 (eyes closed); and five occasional AUs (AU12 (lip corner puller), AU20 (lip stretcher), AU25 (lips part), AU26 (jaw drop) and AU27 (mouth stretch)] [43] were manipulated using Blender to create the dynamic facial expression of pain. Each video began with the character showing an expression of pain at 40% of maximal intensity. The level of the AUs were increased linearly to reach 60% of maximal intensity over a period of 400 ms (ms). The expression of pain was then maintained for 600 ms until the end of the clip (see Fig. 1).

2.3.2. Body Animation

In the *Idle condition*, the character's body was animated with pre-recorded human postural oscillations, i.e., movements resulting from dynamic human equilibrium and breathing [35,44]. For the *Still (neutral) condition*, the character's body was fixed at the initial posture in the pre-recorded motion capture sequence. (see the method section of Treal et al., 2021 for details).

"Motion capture data: kinematic data were collected on a young man (age = 20, with anthropometric characteristics similar to the virtual character). He was instructed to stand naturally with his arms alongside his body without moving his feet and looking straight ahead. Data were collected using a Qualisys optoelectronic motion capture system (Göteborg, Sweden) composed of eight infrared cameras sampled at 50 Hz. Markers were placed on the following anatomical landmarks: head of the fifth and first metatarsals, medial and lateral malleolus, medial and lateral femoral condyles, anterior superior iliac spine, zyphoid process at the lower part of the sternum, L5, C7, nasion, acromion process, olecranon, processus styloideus of the ulna and radius [45]. Three more markers were added to record respiratory movements: two on the sternal extremity of the clavicle and one on the navel. The markers' positions were imported and applied on a virtual skeleton to animate the character using Blender® (Blender Foundation, Amsterdam, Netherlands). The corporeal envelope of the character was mapped on the skeleton in Blender and the link between the envelope and the skeleton was set using the "automatic weighted" option available in Blender" (taken from Treal et al., [38], p3 with authors' permission). For a visualisation of postural oscillations on the virtual human, see the online version of Treal et al., [38], Supplementary Information 2 to 6: https://doi.org/10.1038/s41598-021-91710-5.

2.4. Task and procedure

Once participants had given their written informed consent, the EEG net was installed, and the impedance gel applied to the electrodes. Participants then received instructions for the task. The task was programmed using Psychopy [46] and displayed on a computer screen (20-inch monitor, 60 Hz refresh state, resolution = 1680 × 1050 pixels) at a viewing distance of 70 cm from the participants. Each trial began with the presentation of a black screen (duration = 1000 ms), followed by a white fixation cross (duration = 1000–1800 ms) and a video clip (duration = 1000 ms). Participants were instructed to look at the fixation cross until the start of the video clip, and not to blink from the beginning of the fixation cross to the end of the video clip. After the video clip,

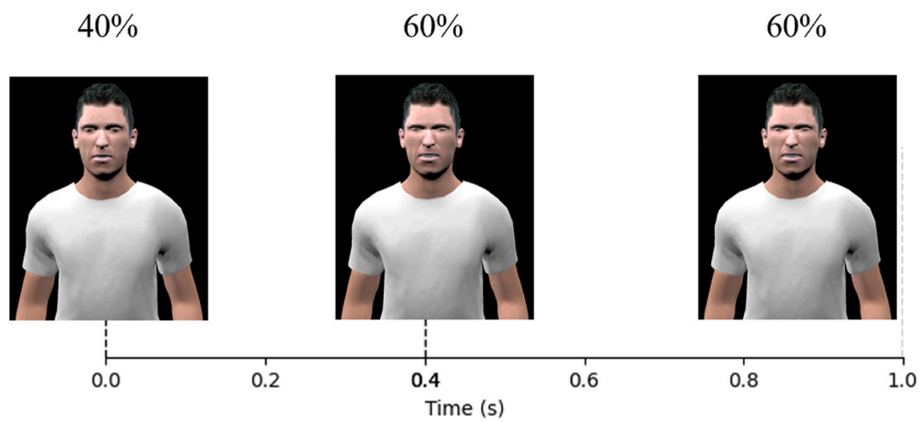

Fig. 1. Left: virtual character's facial expression of pain at the beginning of the clip (AUs at 40% of maximum contraction). Middle and right: virtual character's facial expression of pain from 400 ms to 1000 ms (AUs at 60% of maximum contraction).

participants were asked to judge the intensity of the character's expression of pain by sliding a cursor along a visual analogue scale (VAS) (Left extremity "Mild pain", Right extremity "Very intense pain" [In French "Douleur peu intense" and "Douleur très intense"]). The cursor was displayed initially in the middle of the VAS. Each stimulus was displayed 100 times for a total of 200 trials for the task (100 trials * two body conditions). The order of stimuli was randomised across the task. After every 20 trials, a pause screen was displayed and participants clicked on a rectangle in the middle of the screen when they were ready to resume the task. Before the experimental phase, participants performed a familiarisation phase composed of 20 trials (10 trials of each condition displayed randomly). Task duration was approximately 30 min.

2.5. Data analysis

Statistical analyses were performed using Scipy [47]. For all statistical analyses, alpha was set at 0.05 and Cohen's *d* was reported as effect size when a paired *t*-test was performed.

2.5.1. Behavioural data analysis

Pain intensity rating. The position of the cursor along the scale was converted into numerical values between 0 ("Mild pain") and 100 ("Very intense pain"). The average pain rating was calculated for each condition of body animation (*Idle* and *Still*). A paired *t*-test was then performed on the pain rating between the *Idle* and *Still conditions*.

2.5.2. ERP preprocessing and analysis

All EEG analyses were performed using MNE-Python0.21 [48]. Data were resampled offline at a frequency of 500 Hz, band pass filtered (0.1 and 40Hz) and an additional 50-Hz notch filter was used to reduce electrical noise. A visual inspection was performed to manually identify bad channels, which were then removed and interpolated. After that, the signal was re-referenced using the average of all electrodes. The epochs were then created using a 100-ms pre-stimulus baseline. Epochs containing eye blinks or values exceeding ±150 μV were excluded from analysis. All data sets per participant contained at least 50 epochs per condition without artefacts (min = 58, mean = 88.03 ± 11.67). Time windows were based on previous studies [13,14,39] and were adjusted using the aggregate grand average from trials of our data [49]. The mean amplitudes of the P2 (185–245 ms) and the N2–N3 (250–400 ms) components were calculated at the fronto-central electrodes (FCz, Cz, FC1, FC2, C1, C2), the LPP (600–1000 ms) component at centro-parietal electrodes (cLPP; Cz, CPz, C1, CP1, C2, CP2; [17]) and right centro-parietal electrodes (rLPP; C4, C6, CP4, CP6; [39]). Two-tailed paired t-tests were then performed on each ERP between the *Idle* and *Still conditions*. If there was a significant difference between potentials, a Pearson correlation was performed between the difference in the significant ERP amplitude in each condition (ERP *Idle* - ERP *Still*) and the difference in the pain judgment in each condition (Pain judgment *Idle* – Pain judgment *Still*). A comparison between the correlations [50] was then performed.

3. Results

3.1. Pain intensity rating

The paired *t*-test revealed that participants rated the expression of pain as significantly more intense in the *Idle condition* (mean = 40.35, 95% CI [32.32, 48.38], std = 18.33) than in the *Still condition* (mean = 38.38, 95% CI [30.11, 46.65], std = 18.88) [t (19) = 3.23, $p = .004$, $d = 0.74$].

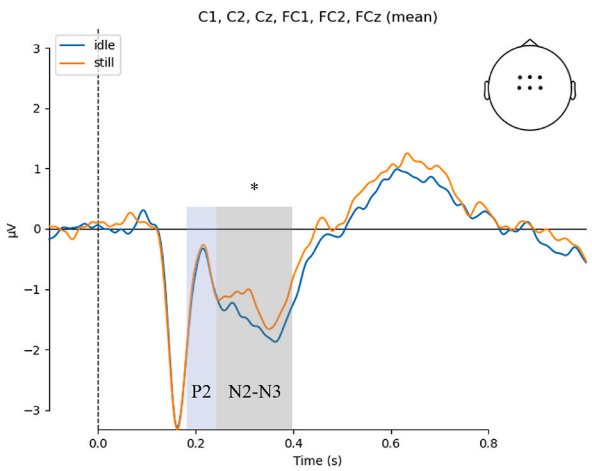

Fig. 2. Average time-course for event-related potentials in the *Idle* and *Still conditions* recorded at the fronto-central electrodes (C1, C2, Cz, FC1, FC2, FCz). (*$p < .05$).

ERPs. P2: The paired *t*-test revealed no significant difference on the P2 component between the *Idle* (mean = −0.77 μV, 95% CI [−1.6, 0.06], std = 2.06) and *Still conditions* (mean = −0.71 μV, 95% CI [−1.47, 0.05], std = 1.92) [t (19) = −0.40, p = .697, d = −0.09] (Fig. 2).

N2–N3: The paired *t*-test revealed that the N2–N3 component was significantly more negative in the *Idle condition* (mean = −1.54 μV, 95% CI [−2.29, −0.79], std = 2.04) than in the *Still condition* (mean = −1.25 μV, 95% CI [−2.00, −0.49], std = 2.06) [t (19) = −2.24, p = .037, d = −0.51] (Fig. 2).

cLPP: The paired *t*-test revealed no significant difference on the cLPP between the *Idle* (mean = 1.81 μV, 95% CI [1.15, 2.47], std = 1.86) and *Still conditions* (mean = 2.1 μV, 95% CI [1.48, 2.71], std = 1.79) [t (19) = −1.11, p = .282, d = −0.25] (Fig. 3).

rLPP: the paired *t*-test revealed that rLPP was significantly more positive in the *Idle condition* (mean = 0.88 μV, 95% CI [0.26, 1.5], std = 1.91) than in the *Still condition* (mean = 0.41 μV, 95% CI [−0.18, 1.01], std = 1.76) [t (19) = 2.42, p = .026, d = 0.56] (Fig. 4).

Pearson correlations between the effect of idle motion on behavioural measures and on significant cerebral measures: Correlations were then performed for the N2–N3 and rLPP ERPs. The difference in the pain rating between *Idle* and *Still conditions* was not significantly correlated with the difference in N2–N3 amplitude between the two conditions [r(19) = 0.25, p = .289]. The difference in the pain rating between the *Idle* and *Still conditions* was significantly correlated with the difference in the rLPP amplitude between the *Idle* and *Still conditions* [r(19) = 0.46, p = .041] (Fig. 5). The difference between these two correlations was not significant (95% CI [−0.66, 0.24]).

4. Discussion

This study aimed to investigate whether idle motion, and specifically biological postural oscillations, would increase the affective expressiveness of a virtual character. The results of an event-related potential (ERP) analysis revealed an increased neural response associated with empathy for its facial pain expression. In line with previous studies [37,38], participants reported perceiving the virtual's character facial expression of pain as more intense when it was animated with biological postural oscillations (*Idle condition*) compared to a condition where its body was fixed (*Still condition*). More importantly, the ERP results showed that both early affective and, contrary to our original hypothesis, late cognitive processes of empathy for pain were affected by the presence of idle motion compared to the *Still condition*. Indeed, the early affective N2–N3 (Fig. 2) and the later cognitive rLPP (Fig. 4) were greater in the *Idle condition* than in the *Still condition*. Interestingly, the difference in rLPP amplitudes between the *Idle* and *Still conditions* was positively correlated with the difference in the pain intensity rating between the *Idle* and *Still conditions* (Fig. 5).

4.1. Idle motion enhanced the affective resonance towards the virtual human's facial expression of pain

As others have proposed [13,39], we suggest that the N2–N3 at fronto-central pooled electrode sites is associated with the affective resonance component of empathy. Our results were consistent with those of previous studies that manipulated stimulus realism using cartoons created from pictures of human hands [12,51]. It is also in line with existing works showing that the neural response associated with affective resonance when viewing someone in pain was modulated by social factors influencing the degree of interpersonal similarity (i.e., ethnicity ([52] for a review) or social membership [53,54]). Moreover, this finding was similar to a recent fMRI study showing that facial expressions of fear in real humans evoked stronger responses in the affective resonance network (ACC, Insula Anterior) than expressions of fear in their avatars [32].

Interestingly, a weaker resonance was reported by Gu & Han [51] in an fMRI study showing that the Anterior Cingulate Cortex (ACC) activity associated with empathy for pain was stronger for the pictures than for the cartoons. The authors interpreted this result

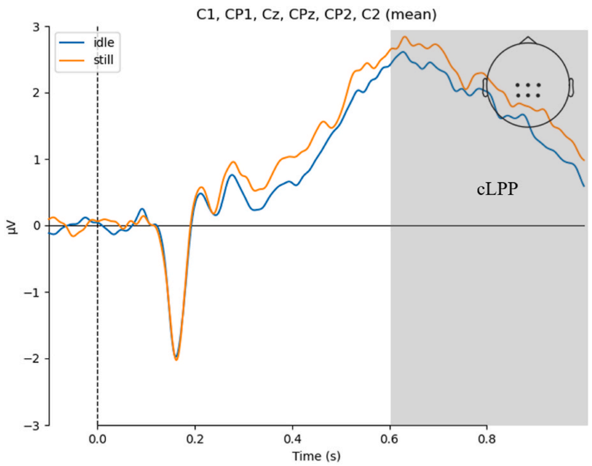

Fig. 3. Average time course for event-related potentials in the *Idle* and *Still conditions* recorded at the centro-parietal electrodes (C1, C2, Cz, CP1, CP2, CPz).

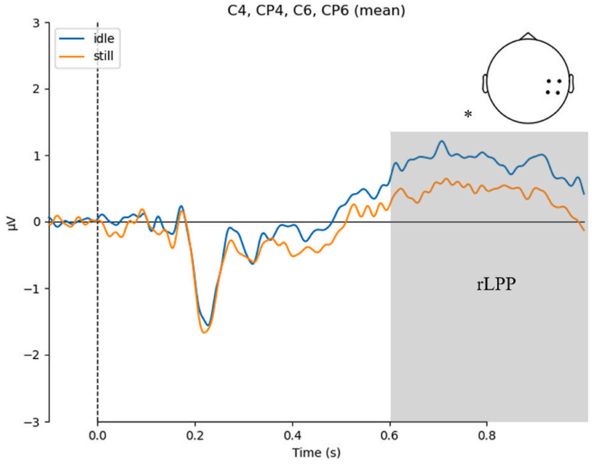

Fig. 4. Average time course for event-related potentials in the *Idle* and *Still conditions* recorded at the right centro-parietal electrodes (C4, C6, CP4, CP6). (* $p < .05$).

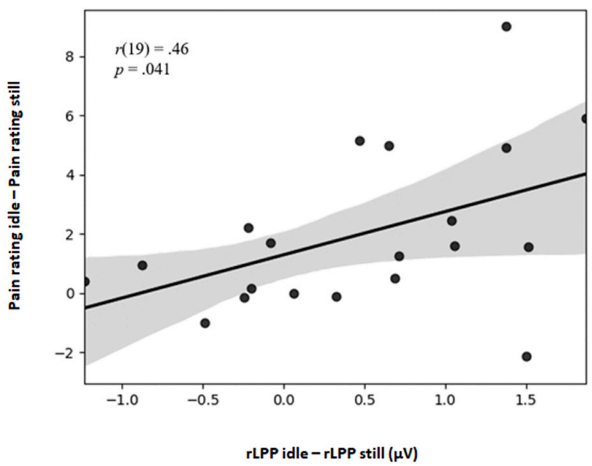

Fig. 5. Correlation between the difference in the pain rating in the *Idle* and *Still conditions* and the difference in right late positive potential (rLPP) amplitude in the *Idle* and *Still conditions*.

in relation with the empathy model proposed by Goubert et al. [55], which distinguished between bottom-up (e.g., features of incoming stimuli) and top-down (features that the observer acknowledges about the situation) processes. They suggested that both processes associated with the decoding of others' pain may lead to differences in brain activation between painful cartoons and painful pictures. Indeed, participants perceived the pictorial divergence between cartoons and pictures (bottom-up processes), and acknowledged that one of the presented stimuli was less realistic (top-down processes). Here, while participants are conscious that the virtual human is not real (top-down processes), the presence of idle motion may have specifically modulated the bottom-up processes by enhancing the virtual character's human-like appearance. Thus, the presence of slight movements would be sufficient to significantly improve the anthropomorphism of the virtual human, inducing a higher resonance when observing the virtual human's expression of pain.

4.2. Idle motion enhanced the cognitive component of empathy for pain

The late cognitive (rLPP) component commonly associated with perspective-taking in the context of pain empathy [14,17,39] was greater when idle movements were added to the virtual human than when its body was fixed. This result was unexpected given previous works exploring the influence of stimuli realism on pain empathy neural correlates [12,32]. Indeed, in Fan & Han [12] the late cognitive component of pain empathy was similar for both painful cartoons and painful pictures. In the same vein, Kegel and collaborators [32] observed no significant differences between virtual and real humans in regions associated with perspective-taking [e.g. Temporo-Parietal Junction (TPJ)], suggesting that the perceptual divergence between virtual and human characters would affect specifically the mechanism underlying affective resonance.

This result on the rLPP could be interpreted in relation with an EEG study that specifically manipulated the degree of anthropomorphism of non-human stimuli (i.e. pictures of vegetables) that were stimulated painfully [39]. Prior to the vegetables being pricked by a needle (painful condition) or touched by a cotton swab (non-painful condition), they were given either a human name to increase their anthropomorphic features (humanisation process) or a neutral adjective (no humanisation). Then, the extent to which participants implicitly associated the stimuli to either a human or an object was assessed in a specific test. Participants who were sensitive to the attribution of these minimal cues of humanness elicited a greater response of the P3 (another ERP associated with perspective-taking) at the right central-parietal electrodes when watching the named vegetables compared to the vegetables assigned an adjective. Here, a similar humanisation process could be associated with the greater rLPP when the pain-expressing virtual character was animated with idle motion compared to when it was still. As already suggested, the presence of idle motion would strengthen the virtual human's anthropomorphism, making it appear more human. This added humanness would have positively influenced the perception of its facial expression of pain, inducing a higher mind attribution to the virtual human, favouring the adoption of its perspective when perceiving its facial expression of pain.

The correlation analyses indicated that the relationship between the effect of idle motion *(i.e. idle condition - still condition)* on participants' pain rating and its effect on the amplitude of rLPP appeared stronger than the relationship between the effect of idle motion on pain ratings and its effect on the amplitude of N2–N3. The former positive correlation suggests that the more idle motion contributed to strengthen mentalising with the virtual character, the more the participants rated the pain as intense compared to the *Still condition. Idle condition* This finding raises the classic question of the relationship between neural and behavioural responses during tasks involving empathy for pain. Evidence of a link between ERP amplitude and subjective reports of other's pain intensity is quite scarce and heterogeneous in the EEG literature [12,17,40]. In this study, the positive correlation between the difference in the idle effect on both other's pain rating and rLPP amplitude, but not with the early N2–N3 component, suggests that the subjective evaluation of others' pain is more closely related with the late cognitive component of empathy. This is consistent with Cheng and collaborators [40], who showed that the LPP amplitude elicited by stimuli of others experiencing pain was significantly correlated with ratings of pain intensity. However, the conclusion regarding a relationship between the cognitive component associated with pain empathy and the judgement of others' pain must be taken with caution due to the small sample size of this study (see *Limitations of the study section below*).

4.3. Towards the use of biological motion for idle animation in virtual characters?

The biological dimension of the idle movements could be primordial in this process of mind attribution, and favour a greater elicitation of empathy for a virtual character. This hypothesis is supported by recent empirical studies showing that biological motion in virtual characters enhanced both their acceptability [56] and visual attention of participants [57] compared to mechanical motion. Moreover, it is consistent with fMRI literature suggesting that the ERPs reflecting perspective-taking were aligned with the rTPJ [14, 58], a cerebral region that would also be related with both the detection of biological motion and the process of mind attribution (Lee & McCarthy, 2016) [59]. When idle motion is implemented in the form of biological motion, it could lead to early categorisation of the virtual character as human, resulting in a greater empathic response to the character's expression of pain. Biological motion would be perceived at an early preattentive stage [60] and then serve as a perceptual 'life detector' [61,62].

4.4. Limitations of the study and suggestions for future research

Spurred by this pilot study, biological idle motion may appear as a relevant tool for enhancing the behavioural realism of a virtual character when interacting with a human person. However, some limitations must be addressed. The main limit concerns the study's sample size. Thus, these preliminary results would have to be confirmed in future studies with a larger sample, particularly to confirm the interpretations of the correlation analysis. Indeed, it is plausible that the correlation between the differences in still and idle conditions concerning pain rating and N2–N3 amplitude may become significant with a larger sample size.

A second limitation of this study is that there was only a single virtual male character throughout the experiment, which could potentially result in a habituation effect. It would be interesting to use several distinct virtual characters, including females, to reduce potential habituation effects, and to examine and/or control for a gender effect when estimating other's pain [63]. Additionally, some studies suggested that users, especially women, would prefer to interact with a female character than with a male character [64,65], which further prompts the use of diverse characters. Moreover, it would be interesting to conduct this experiment with different affective states to examine whether the impact of idle motion on affective resonance can be generalised to other negative non-verbal expressions such as fear, positive emotions such as joy, or more complex emotions such as boredom.

Finally, further studies directly comparing biological and mechanical idle motion are required to examine whether the biological dimension of idle movements (and if so, which attributes of these movements) influence the way we empathise with the virtual human. Another hypothesis that remains to be tested is whether the biological dimension (taken from actual human movement) of idle motion would be a necessary element for the 'suspension of disbelief' when using virtual humans in emotion research. Suspension of disbelief requires accepting that a virtual human can think and feel emotions, attributing a mind to it despite being fully conscious of its unreal nature [24]. This appears essential for the validation of paradigms using virtual humans. The link between greater pain empathy for a virtual human and the phenomenon of suspension of disbelief is speculative and needs to be verified in future works.

5. Conclusion

The field of human-machine interactions may benefit from the development of more realistic agents in the context of empathy research, which is focused on making their emotion appear more genuine in order to provoke a spontaneous reaction from participants. In this context, a new problematic is emerging, examining the potential of idle motion, in particular, biological postural oscillations reproducing human dynamic equilibrium, to strengthen the illusion that a virtual human may really feel the emotion that it is expressing. Taken together, these results confirm the usefulness of idle motion to create a more ecological emotional reaction to a virtual human expressing pain. Based on the bulk of evidence showing that the visual system is particularly sensitive to biological motion, it was argued that biological motion would appear as a powerful signature of humanness, and thus, might be decisive in enhancing the behavioural realism of a virtual human. In addition to its theoretical issues, improving the behavioural realism of virtual humans may be important when using such virtual platforms in applied contexts, such as a tool for the remediation of social cognition disorders (autism, schizophrenia) or to train clinical empathy in healthcare providers.

Declarations

The study was approved by the Ethics Committee of Paris-Saclay University (#CER-Paris-Saclay-2020-147).

Author contribution statement

Thomas Tréal: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Philip L. Jackson: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Aurore MEUGNOT: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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