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The effect of social settings and olfactory environments on spontaneous movement synchrony

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Interpersonal synchrony refers to the temporal coordination between two individuals, signaling the coupling of their behaviors. Optimal movement synchrony in dyads is linked to more affiliative behavior, cooperation, and trust. However, there is limited research on how the sensory environment impacts interpersonal synchrony. One significant environmental factor influencing human behavior and social interactions is ambient odors. This study aimed to examine the effect of ambient odor on interpersonal synchrony, particularly in-phase movement synchrony. Motion energy analysis and windowed cross-correlations were used to measure synchrony levels between participants during video-recorded interactions. Twenty-five same-sex friend dyads performed three interaction tasks designed to create fun, cooperative, or competitive atmospheres. These tasks were conducted with a pleasant, stimulating peppermint odor or in a control condition without odor. Consistent with previous studies, higher synchrony levels were observed in fun atmospheres compared to competitive and cooperative ones. No significant effects of odor stimulation were found. Overall, the results confirm that social context significantly influences movement synchrony and affiliation, while ambient odor might not affect interpersonal synchrony, at least when the odor is irrelevant to the task.

Keywords Behavioral synchrony, Olfactive stimuli, In-phase synchrony, Anti-phase synchrony, Cooperation, Competition

Interpersonal synchrony is a prevalent phenomenon that is present in various types of human interactions and social contexts. For example, it can naturally arise during concerts, where rhythm and energy create a unique collective experience[1]. In childhood, spontaneous synchronization processes are thought to be linked to attachment and a feeling of connection with others. The ability of children to synchronize their gaze, movements, and speech emerges within the first few years of life[2]. Defined by DaSilva & Wood as the alignment of behavior and/or physiology during interactions[3], interactional synchrony may occur at various levels of human interaction. Thus, synchrony may emerge as the temporally coordinated dynamics of either movement, vocal parameters, physiological markers, or other nonverbal indicators in interacting individuals.

The neuroscientific literature has reported inter-brain synchrony[4], which corresponds to the synchronization over time of two partners' central nervous systems. Physiological synchrony has been studied based on peripheral measures such as heart rate and electrodermal activity[5,6]. Finally, changes in an individual's body posture often led to corresponding changes in the other person's body posture, whether the two were friends, strangers, or spouses[7], making movement synchrony an important aspect to study during social interaction. Movement synchrony, a specific type of interpersonal synchrony, is reflected by the temporal aligning of a given motor action among two or more interacting individuals[8]—people often mirror each other's movements in a time-correlated way. This phenomenon can be observed in everyday-life situations, such as when nodding in agreement, shaking one's leg, or shifting posture when sitting during face-to-face discussions. For example, if during a walk, one partner begins to increase walking speed, the other is likely to increase walking pace to maintain synchrony within a few seconds, without even realizing but with the intention to facilitate communication.

The notion of movement synchrony was early introduced by Condon and Ogston[9]. In their study, manual coding was applied to register changes in movement and posture occurring between frames of film recordings. A various range of paper-based methods relied on judges who provided independent evaluations based on video recordings[10,11]. With the evolution of video technology, movement synchrony has since been extensively studied

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both in dyads and in larger groups using video recordings and frame tagging[12–15]. However, these approaches are bound to observational errors and do not always provide the means to detect the slight changes in movement synchrony, namely the intensity and direction of correlational changes.

Over the last ten years, a new method to quantify behavioral synchrony using motion energy analysis (MEA) has emerged. MEA is an objective method that provides the means to determine changes in the quantity of movement within a given time series. This approach is an efficient alternative to manual ratings by an observer—which takes time and is prone to errors[16]. Using the MEA software, it is possible to upload videos and define regions of interest (ROI) and the software automatically calculates the quantity of changing pixels detected within the pre-defined ROIs as a measure of motion. MEA provides the motion time series of both interacting partners, which can then be used to compute movement quantity and synchrony between the two participants.

Movement synchrony in dyads is crucial in a range of situations throughout social life. Firstly, synchrony between two people is associated to cooperation during a wide number of tasks. Dyads composed of same-sex strangers revealed more absolute movement synchrony when talking about things they both disliked in a fun context rather than having a debate with two opposite positions[16]. Other studies have reported that synchronized actions lead to more cooperation than non-synchronized activities[14]. In an experimental study in which participants walked around the campus together, synchronized footsteps later predicted donations in a game involving trust and requiring individual sacrifice for group benefits[17]. Hence, it is thought that time periods during which movement synchrony takes place may support the experience of sharing a common goal[18].

Synchrony between people impacts liking, trust, and other affiliative behaviors. In collective gatherings, higher perceived emotional synchrony was associated with stronger social support, and higher endorsement of social beliefs and values, reinforcing the identity fusion of the group[19]. The literature also revealed an influence of synchrony on perceived similarity and connectedness[14]. More specifically, a meta-analysis of 42 studies on behavioral synchrony reported that, when compared to non-synchronous conditions, synchrony increased prosocial behaviors, social cognition, perceived social bonding, and positive affective states[7]. Movement synchrony has also been suggested to play a role in mate choice, with evidence indicating its influence on attraction and relationship formation[20,21]. The effect of movement synchrony on social interaction was found to emerge even when individuals are unaware of the spontaneous synchronization phenomenon[16]. A possible explanation of this effect might be that synchrony facilitates incidental memory for speech and appearance of the second partner[22]. A richer memory representation of the person and interactional experience would increase the emotional experience and associated empathy. A second hypothesis is that interpersonal synchrony and positive affective states create a better environment for interactions. As for causal direction, findings supported the interpretation that synchrony facilitates the emergence of positive affective states[16].

Taken together, the above-mentioned studies support the key role of movement synchrony for positive social cohesion. These findings open the door to numerous perspectives in health and social psychology. A key question is now whether it is possible to modulate—and especially improve—social interaction by changing the degree of synchrony between individuals during a social task. For this, we must arrive at a better understanding of the environmental factors that influence the level of synchrony between individuals. This question has surprisingly triggered very few studies. The scientific literature describes the relation between synchrony and other factors such as cooperation and empathy, but to our knowledge, no studies have tried to use augmented sensory environments to enhance movement synchrony between two individuals.

An environmental factor that could modulate the level of movement synchrony is odors. The sense of smell is phylogenetically the oldest sensory system and has important implications for survival instincts by influencing motor execution through approach and avoidance behaviors[23]. In addition to influencing our emotions and movements, odors can indeed influence social behaviors. Research examining the effect of odors on social interaction showed that pleasant odors were associated with altruistic behaviors. More specifically, Baron reported that participants surrounded by a pleasant odor were more likely to spontaneously help a stranger than when no odor was diffused[24]. Odors can influence problem-solving, as unpleasant odors have been shown to decrease cooperation between individuals[25]. The few scientific studies published in the field of social psychology have highlighted the possibility that when asked to solve a problem in a room where a pleasant odor is diffused, a group tends to set higher goals, make more concessions, and is overall more efficient[26]. Given that peppermint odor is known to heighten arousal and attentional focus, it may not only increase overall movement but also facilitate greater synchrony between interacting partners by reinforcing social efficiency, altruism and shared engagement in the task[27]. The aim of the present study was to assess whether the use of an ambient pleasant peppermint odor could modulate movement synchrony during three face-to-face social tasks.

We hypothesized that perceived arousal and positive valence will be higher in the odor conditions than in the no-odor conditions (H_1). In addition, the fun task will increase positive valence in comparison to the competition and cooperation tasks (H_2). The third hypothesis states that the participants will move more in the odor condition than in the no-odor condition (H_3). Diffusing a peppermint odor in the environment will also increase movement synchrony in all tasks (i.e., cooperative, fun, and competitive tasks; H_4). Following the findings of Tschacher et al.[16], a fun atmosphere enhances the degree of interpersonal synchronization in dyads; thus, we hypothesized that movement synchrony will be higher in dyads in the fun task than in the cooperation and competition tasks (H_5).

Results

The results reported hereafter concern the characterization of affective states, quantity of spontaneous movement and the degree of movement synchrony in the cooperative, fun, and competitive tasks produced in odor and no-odor environments. Overall, there were no significant effects of order. Hence, mean results are reported.

Affective states

The median scores of the rating for the perceived affective states obtained from the affect grid are presented in Fig. 1, for arousal (*bottom*) and valence (*top*).

Valence

The RM ANOVA showed a significant effect of Task on perceived valence, $F(1,50) = 5.11$, $p = 0.028$, $\eta^2_p = 0.09$, with higher scores of positive affective valence in the fun task (n = 100, $M = 7.270$, $SD = 1.462$) than in the cooperation (n = 100, $M = 6.760$, $SD = 1.154$) and competition tasks (n = 100, $M = 6.960$, $SD = 1.415$). Post hoc analyses confirmed that perceived valence in the fun task was significantly higher than in the competition task ($t = -2.917$, $p = 0.011$), while no significant differences were observed between the cooperation and fun tasks ($t = -1.74$, $p = 0.249$) or the cooperation and competition tasks ($t = -1.177$, $p = 0.720$). The effect of Odor and the Odor × Task interaction were nonsignificant ($p = 0.457$ and $p = 0.807$, respectively). Overall, the results indicated that participants reported more pleasure when engaging in the fun task than in the two other tasks. Ambient positive odors did not significantly change the pleasantness of the experience.

Arousal

The RM ANOVA did not reveal a significant effect of Task ($p = 0.188$), Odor ($p = 0.527$), or Odor × Task interaction ($p = 0.347$) on perceived arousal. Overall, these results indicated that there were no changes in the perceived arousal levels across experimental conditions.

Quantity of body movement

The mean sum of movement is depicted in Fig. 2 as a function of the task. The RM ANOVA showed a significant effect of Task on the sum of movements ($F(2, 215534) = 2030.83$, $p < 0.001$, $\eta^2 = 0.009$), with more movements observed in the competition task ($M = 366.423$, $SD = 373.089$) than in the cooperation ($M = 302.832$, $SD = 368.406$) and the fun tasks ($M = 321.853$, $SD = 386.900$). Post hoc tests revealed that movements were significantly higher in the competition task compared to both cooperation ($t = 63.781$, $p < 0.001$) and fun tasks ($t = 42.373$, $p < 0.001$). Additionally, the cooperation task resulted in significantly fewer movements than the fun task ($t = -18.589$, $p < 0.001$).

The effect of Odor and the Odor x Task interaction were nonsignificant ($p = 0.347$ and $p = 0.698$, respectively). Overall, the results indicated that participants moved more during the competition task than during the fun and cooperation tasks. Ambient odor did not influence the quantity of spontaneous body movements across participants.

Degree and nature of movement synchrony

Figure 3 (left) presents an illustration of descriptive results of the movement time series obtained in two participants (P01 and P02) of a typical dyad (D11). On the y axis, one can see the quantity of movement recorded

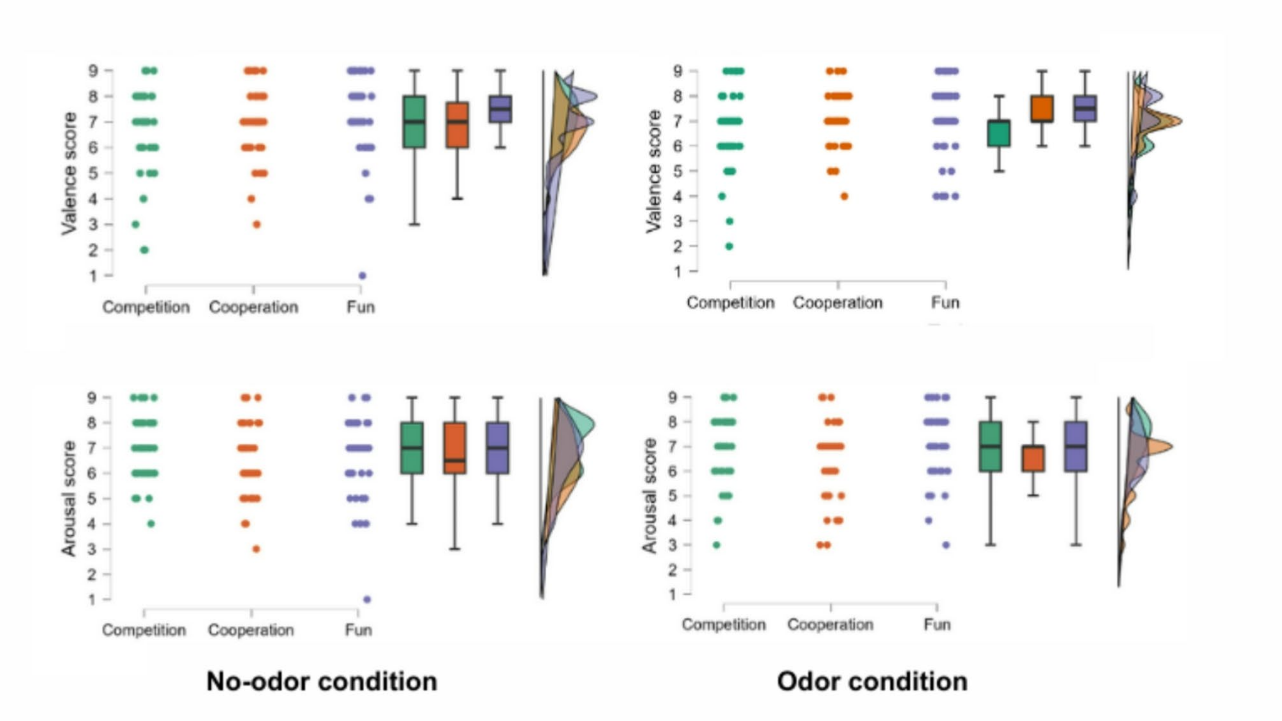

Fig. 1. Mean valence scores (top) and arousal scores (bottom) as a function of task (Competitive, Cooperative, Fun) when engaging in an ambient odor environment (right) or an ambient odorless environment (left).

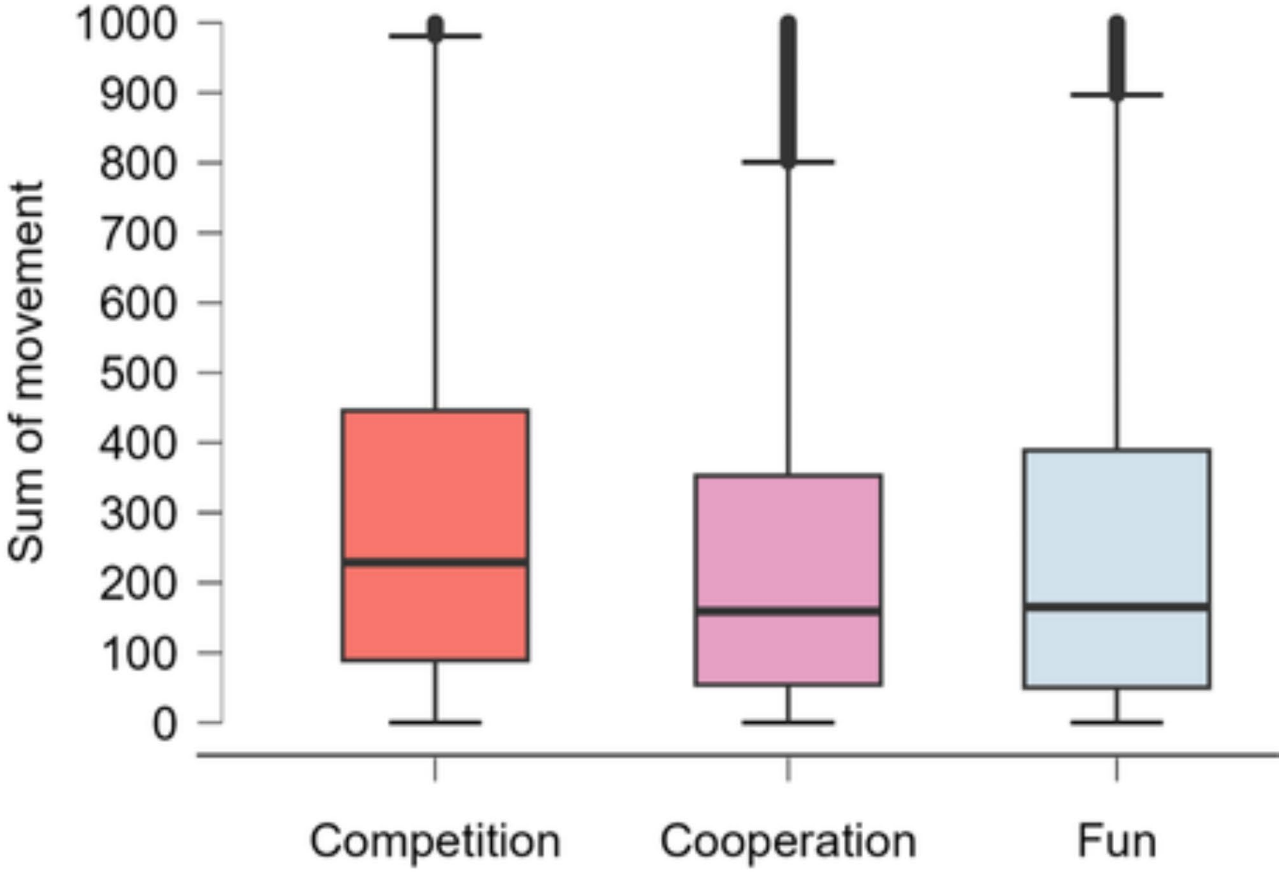

Fig. 2. Mean sum of spontaneous body movements as a function of task (Fun, Cooperative, Competitive).

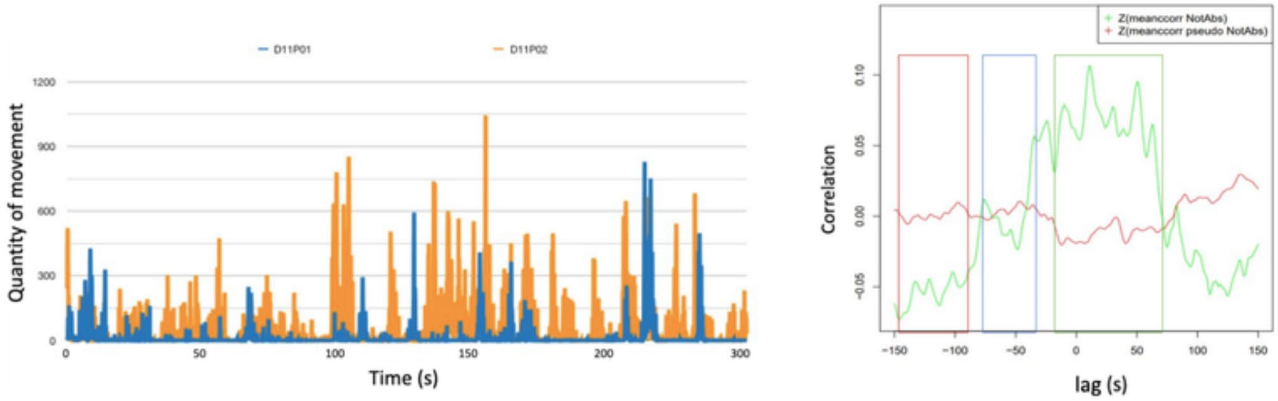

Fig. 3. LEFT PANEL: Visualization of the quantity of movement over time (in seconds) for two individuals in the same dyad performing the ‘Fun’ task. RIGHT PANEL: Results from the SUSY algorithm applied to the raw data to compute the mean synchrony values (green curve) and to the shuffled data to compute mean pseudo-synchrony values (red curve) as a function of event lag. The three boxes in the right panel highlight periods of different synchrony states: the red box indicates anti-phase synchrony (correlation below pseudo-randomized data), the blue box indicates no synchrony (similar synchrony and pseudo-synchrony levels), and the green box indicates in-phase synchrony (correlation above pseudo-randomized data).

by motion energy analysis across time (s). The SUSY software then calculates the cross-correlations between participants. Figure 3 (right) presents the true data (presented in green) that was obtained for the typical dyad 11. To control for random or coincidental synchrony, SUSY also enables the calculation of shuffled data (presented in red). The comparison between the true and the shuffled data indicates the level of true synchrony that was used in the following to obtain the main statistical results. We also present in Fig. 3 (right) three windows to illustrate the typical patterns that would be expected for anti-phase synchrony (red block), absence of synchrony (blue block) and for in-phase synchrony (green block).

The statistical results are presented here after. When contrasted to 0, the student t-test showed a significant level of movement in-phase synchrony in the fun task ($t = 5.547$, $p < 0.001$) but not in the competition ($t = -1.174$, $p = 0.246$) or in the cooperative tasks ($t = -0.887$, $p = 0.379$). When examining the effect of odor presence, movement synchrony levels did not differ from 0 in either the odor ($t = 1.704$, $p = 0.093$) or the no-odor conditions ($t = 1.534$, $p = 0.129$).

The mixed-effects model indicated a significant effect of Task on the level and the sign of movement synchrony (ES[no-abs]), $F(2,25) = 19.84$, $p < 0.001$, with more in-phase synchrony in the fun task ($n = 25$, $M = 4.559$, $SD = 6.672$) than in the cooperation task ($M = -0.655$, $SD = 5.159$). Results indicated a tendency towards anti-phase synchrony for the competition task only ($n = 25$, $M = -1.550$, $SD = 5.409$). Post hoc analyses confirmed that movement synchrony in the fun task was significantly higher than in both the competition ($t = -5.098$, $p < 0.001$) and the cooperation tasks ($t = -5.036$, $p < 0.001$), while no significant differences were found between the competition and cooperation tasks ($t = -0.062$, $p = 0.998$). The main effect of Odor was nonsignificant ($p = 0.274$). Mean effects are reported in Fig. 4.

Discussion

We explored the presence of movement synchrony in dyads of same-sex friends who came together to the laboratory and engaged in three games. The tasks were performed in a room with or without ambient peppermint odor. The main objective of this research was to assess whether movement synchrony would be greater during a pro-social task and whether this phenomenon would be further enhanced by the presence of pleasant odors. Overall, the results on the task effect indicated that participants moved more in competition but synchronized more in the fun task. The fun task was found to be associated with more positive affective states, confirming H_2. These results replicate in a sample of dyads of friends the same task effect as reported by Tschacher et al.[16] for which dyads of strangers were recruited. Nevertheless, in their study, movement synchrony was analyzed only on absolute values. As a result, it was not known to date whether synchrony was due to in-phase or anti-phase synchronization phenomena.

When two individuals become coordinated, two contrasting modes of synchrony can emerge[28]: in-phase synchrony (i.e., covariations of the indicators occurring in the same direction) and anti-phase synchrony (i.e., covariations of the indicators occurring in the opposite direction). Many studies in the field of social interaction have focused on synchrony without differentiating in-phase from anti-phase synchrony. However, in-phase and anti-phase intervals may serve different functions and play contrasting roles in the embodied experience of social interaction[6]. Hence, to gain a true picture of the interactional phenomenon, it is necessary to adopt a tool that provides the means to dissociate anti-phase and in-phase synchrony. In the present study, we employed the Surrogate Synchrony (SUSY) statistical software, which allows for the differentiation between these two types of synchrony. Results indicated a tendency towards anti-phase synchrony in the competition task (i.e., the movement of participant A and B co-varied in the opposite direction indicating that, when participant A moved more, participant B moved less). In the fun social setting, our dyads presented higher levels of in-phase interpersonal synchrony (i.e., the movement of participant A and B co-varied in the same direction). These findings confirmed H_5; they stress the importance of looking at direction of co-variations by reporting a key role played by in-phase synchrony for pro-social behaviors. Specifically, in previous work, in-phase movement synchrony was reported to be triggered by asking participants to synchronize intentionally their movements to the movements of another[14,17]. The results of these studies demonstrated a beneficial effect of in-phase synchronization on cooperation, social attachment, cohesion, positive affect, and affiliative behaviors. For future work, it would be of interest to study in greater depth the functional relation between affective states and in-phase synchrony to clarify their causal relationship and influence on pro-social attitudes.

To measure and compute the level of spontaneous movement synchrony, motion energy analysis (MEA) was used in the present study. As a quantification tool of movement quantity and motor synchrony, MEA has the advantage of being objective and thus, free of a rater's interpretation of the meanings of nonverbal gestures and posture shifts. MEA also provides the means to dissociate between in-phase and anti-phase synchrony in a natural setting without interfering in the face-to-face interaction. In the present study, we defined the body of each individual as the critical region of interest (ROI). It is the case that MEA offers also the means to delimitate sub-ROIs (e.g., head, foot, upper body, etc.). For example, Ramseyer and Tschacher reported that during therapy-patient interactions, head synchrony better predicted therapy outcome than lower body synchrony, with longer lasting effects with head synchrony specifically[29]. However, to use sub-ROIs there is a necessity to set a strong constraint on individuals' freedom to move. To ensure sound data, the sub-ROIs must remain stationary from one frame to the next within the video sequences. In the stationary MEA version, the sub-ROI frames do not adapt dynamically to body shifts. Hence, in the present study, we could not investigate whether sub-ROI synchrony took place. In future studies, a dynamic MEA version could be developed by taking advantage of the automatic visual tracking algorithms that are today being implemented in motion-capture technologies[30]. Then, it would be of interest to confirm the in-phase effects of the fun task on upper-body specifically, without the need to constrain participants from using nonverbal gestures during social engagement. Such a tool would open new perspectives for the modeling of dynamics of in-phase synchrony across body segments in natural settings.

Effects of ambient odors

There was an absence of effect of the peppermint odor. Hence, H_1, H_3 and H_4 were not confirmed. Nevertheless, we took care to verify that the ambient peppermint smell was above threshold and was consciously perceived by the majority of the participants. A total of 65% of the participants even recognized the smell as mint. Hence,

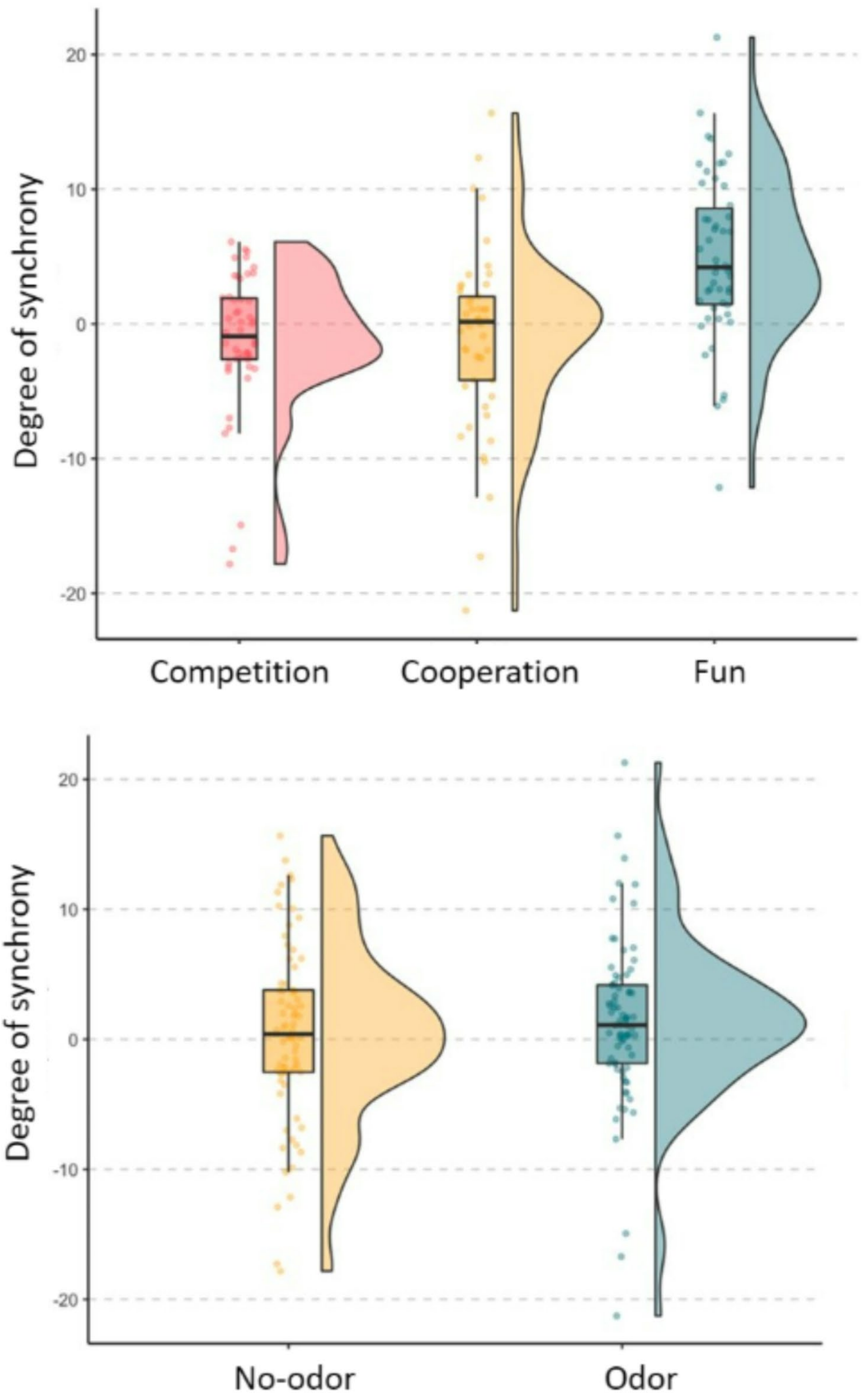

Fig. 4. Mean degrees of synchrony as a function of task (Top panel) and ambient odor environment (Bottom panel).

it seems that in a social task that requires cognitive engagement, the odor environment had little impact on the pleasantness of the experience. Furthermore, the odor environment impacted neither the quantity of expressed movement nor the degree of motor synchrony.

The absence of an odor effect may be related first to the choice of the odor itself. Peppermint is a stimulating odor that increases alertness and oxygen intake by opening the lung cage[27]. Peppermint-odor environments have been reported in clinical settings to allow participants to reduce their sensation of fatigue and improve mood[31,32]. Peppermint ranks highly in self-rated scales, being reported as very pleasant, intense, and highly stimulating[33]. Peppermint odor is also known to enhance physical performance in athletes, such as first division Brazilian soccer players[34]. However, in our study, the task was cognitive. Hence, peppermint-odor may have an impact in situations for which the physiological system needs to respond, but it may not be instrumental for the cognitive load of social interaction.

Mechanisms of attention serve to facilitate the selection of appropriate events from noisy environments encountered during everyday activities. Indeed, there is a common and limited pool of attentional resources for the processing of sensory information such as visual, audio and olfactive stimuli[35]. Humans direct an attentional spotlight within spatial coordinates that are near them, in both vision and audition. Some studies suggest that odors do not capture attention under the same principles[36,37]. In social tasks that do not involve olfactory stimuli, the need for olfactory selective attention is limited, and therefore, the spatial focus on olfactory stimuli is less relevant[38]. For example, in a study presenting neutral pictures, participants were asked to report which sensory changes occurred in the environment. While many participants reported a manipulation in luminance which did not occur, only three out of 93 noticed the manipulation of smell[39]. Humans are characterized by a very strong visual specialization, as is the case for most primates, making visual stimuli more likely to capture attention in social tasks than odorant stimuli[40]. Nevertheless, a few studies have reported the power of negative odors to trigger behavior changes[41,42]. It would be of interest in future studies to test whether unpleasant odors would have a stronger power to capture attention than pleasant peppermint.

Another possible explanation for the absence of an odor effect in the present study is that peppermint is not an odor that is encountered naturally, especially, in a laboratory room. Thus, the unexpected nature of the odor in our specific context may have turned the ambient peppermint odor into a nonrelevant stimulus. Most participants would then have unconsciously considered the odor as something to be ignored. It may be relevant to consider in future experimental designs the nature of the ambient odor as a function of task and context. Masculine body odors have been reported to have a powerful effect on female arousal intensity[43]. Hence, body odors for example could be chosen specifically to modulate motor synchronization as the odor could play a magnetic role in the degree and nature of social relationships (sweat, stress and fashion perfume are not characterized by similar odor molecules[44]). In our view, a better understanding of olfactory capture of attention for behavior modulations requires that future work consider the odor context as primary and create more ecological situations. In this sense, the smell of caffeine could be considered in the future, as caffeine odor tends to enhance cognitive activity[45]. As such, participants could be invited to perform the social tasks described here in a coffee shop, i.e., a place for which the odor of caffeine is expected. The ambient odor would here be coherent with a high congruency between the workspace and the task; Caffeine could then function as a true booster of motor synchronization through automatic capture of olfactory attention.

Implications and conclusion

The study of interpersonal synchrony has important social and clinical implications. Humans are individuals that are born and grow to be social; both physical and mental wellbeing are crucially needed to insure good social functioning. Understanding social processes, such as interpersonal synchrony, is essential to better comprehend adaptive social relationships. In many common situations (e.g., stressful workplaces), social synchrony is impaired[46]. The same is evident in different pathologies, such as in autism spectrum disorders[47,48], maternal depression[49], schizophrenia or social anxiety disorder[50]. Given the implications of synchrony in human interactions, the comprehension of how augmented sensory environments can modulate or even enhance the degree of interpersonal synchrony in dyads is crucial to improve social integration in the general population, and in clinical populations in particular. The study of interpersonal synchrony has also implications for the clinical training of psychologists, psychiatrists and other health professionals. Nonverbal behaviors are considered as a predictor of clinical effectiveness and patient outcomes[51]. Thus, a deeper knowledge of the interplay between in-phase synchrony and the environmental factors is a scientific avenue to be encouraged.

The findings reported here confirm that movement synchrony is enhanced when participants freely engage in a fun cognitive task that emphasizes the needs/abilities of listening, speaking and dialog engagement. Our findings showed that in-phase synchrony characterizes the positive phenomenon of social interaction, which was the case here in the fun condition. Competition, on the other hand, was tagged with greater quantities of movement and absence of movement synchrony between the two participants. The limited effects of odors on movement synchrony should encourage future research in the field of olfactory neurosciences to gain in time a better understanding of how odors influence the dynamics of human spontaneous synchronization. Nevertheless, we describe here a series of ecological social tasks, with sound experimental methods, and adequate statistical power. This procedure has the potential to guide future studies on how to select ambient odor environments to modulate interpersonal synchrony.

Method

Participants

Healthy adults were recruited for the present study from the staff and student corpus of the university of Lille (France). Recruitment also included participants from the researchers' networks and volunteers who responded to the study's advertisement shared on various social networks. Each participant was asked to come to the laboratory with a friend of the same gender. The two participants were referred to as a dyad. In order to participate in the study, participants had to be free of any motor dysfunction or neurological, auditory, and olfactory disorders. Concerning COVID-19 restrictions, a letter of information regarding COVID-19 was completed by each participant.

The sample size required for this study was calculated using G*Power (3.1.9.2). The theoretical sample size was computed for a repeated-measured analysis of variance (RM ANOVA), with the results of Tschacher et al.[16]

for the task effect and Marchlewska et al.[25] for the odor effect as group parameters. The power analysis indicated that a minimum of 18 dyads were required for the task effect ($f = 0.56$; $\alpha = 0.05$; $1-\beta = 0.85$) and a minimum of 22 dyads for the odor effect ($f = 0.314$; $\alpha = 0.05$; $1-\beta = 0.85$). We conformed to the larger number between both effects, resulting in a 22-dyads required sample size. Three additional dyads were collected to account for eventual outliers and technical issues. In total, 25 same-sex dyads carried out the experiment, with a majority of female dyads in the sample ($n = 20$).

The study was conducted in accordance with the Declaration of Helsinki. All participants received an information letter and gave written informed consent prior to their inclusion in the single experimental session. In addition, all participants filled out a permission form to be video-recorded and informed consent was obtained to publish blurred images in an online open access publication. The study was approved by the ethics committee of the University of Lille (reference 2017-233-S52, NIRS Sensations 20/01/2022 addendum).

Procedure

Experiment

Upon arrival at the laboratory, the session structure was explained to the participants and the experimenter made sure that both individuals clearly understood the task at hand by asking point-to-point questions.

Each dyad participated in three different tasks: cooperation, competition, and fun discussion. The tasks were presented in a semi-randomized order. Within each task situation, the dyad performed under two conditions: odor and no-odor trials. Hence, a total of six experimental conditions were performed by each dyad (see Fig. 5). Each condition included a 2-min baseline followed by the 5-min conversation task. These time intervals were applied systematically in all six conditions (Task(3) * Odor (2)). In the odor conditions, diffusion of the olfactive stimuli began at the start of the task, immediately after the baseline. Hence, there was always at least a 2-min time interval to set a clean and stable odorant environment. Half of the dyads performed the odor condition before the no-odor condition. The other half of the dyads started each task by the no-odor condition and then, performed the odor condition. We applied this order manipulation to control for possible learning effects, as the participants needed to repeat each task twice. In the present study, we used peppermint odor, and the perfume was diffused at above threshold for all individuals using olfactory speakers (Olfahome E140, OdoraVision).

Task

The cooperation task was aimed to develop cooperation within the dyads. Participants randomly drew a social or political topic of common interest from an urn (without replacement). Eight different topics were prepared, e.g., "for or against compulsory military service?"; "For or against pocket money for children?". These topics provided the basis for a verbal debate. Each participant was provided with one of two opposing written lists of specific arguments fitting these topics, which they could read in a 2-min preparation period prior to the start of the trial. The cooperation instruction was to develop a shared position with the strongest arguments from the lists.

In the competition task, the process was similar, with a list of arguments for and against a specific topic handed out to the participants. The competition instruction was to argue as convincingly as possible against the position of their partner. Unlike in the cooperation condition, participants were instructed not to reach a compromise. The competitive setting was also pressured by the experimenter, who instructed each participant to win the debate. For example, the experimenter said "May the best win" before the beginning of each trial.

The aim of the fun task was to create a comfortable, pleasant atmosphere similar to that experienced in a humorous, joyful situation among friends. Participants received instructions to design a five-course meal, or a

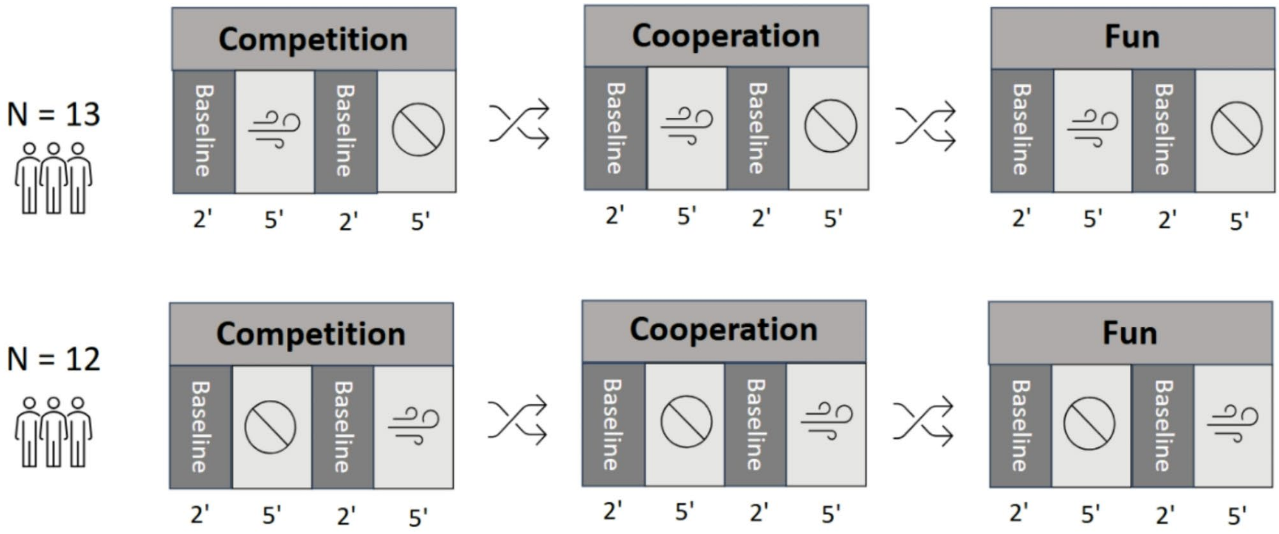

Fig. 5. Diagrammatic representation of the experimental design for the three interaction tasks promoting either a competitive, cooperative, or fun social atmosphere.

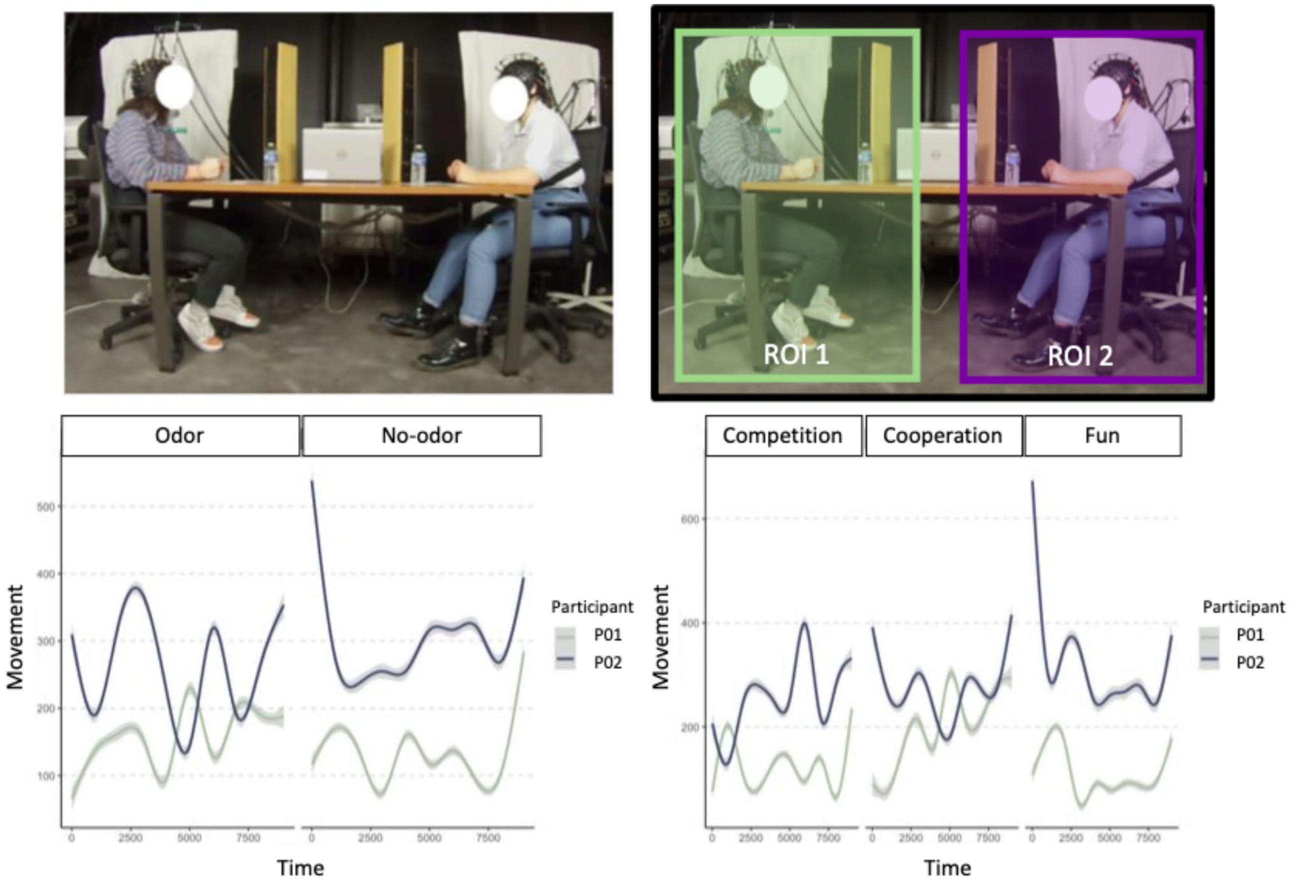

Fig. 6. Illustration for a unique typical dyad of the output from the Motion Energy Analysis (MEA). The top panel (left) shows a clip from the video recording, while the right panel displays the corresponding image from the MEA software with the two defined regions of interest (ROIs). The bottom panel illustrates a typical time series of individual motion energies, for the two participants, as a function of the presence of odor (left) and task condition (right).

music playlist composed of five songs. The instruction was for the dyad to decide on dishes or songs that both friends definitely *dis*liked.

Materials

Questionnaires

After each experimental condition, participants were asked to indicate their valence and arousal levels on the affect grid[52]. In this grid, valence and arousal are rated on a scale from 1 to 9. For valence, a score of 1 represents strong negative affect, 5 a neutral state and 9 strong positive affect. For arousal, 1 represents a low level of arousal, 5 a neutral state and 9 a high level of arousal. Examples were given to the participants so that they could better understand what was meant by arousal and valence. These scores were used to assess whether the odor environment and/or tasks had a specific effect on the way each participant experienced the session (H_1 and H_2).

Equipment

The experimental sessions were filmed using a portable camera (GoPro HERO4 v05.00, GoPro USA) at a sampling rate of 30 Hz. The technical prerequisites for the video recordings used by MEA software[53] are a static camera position and stable light conditions with constant shutter-speed and aperture. To ensure that regions of interest (ROIs) would not overlap, and people would not occlude one another on the video, participants were separated by a table of 1.5 m. Any object likely to move was removed from the camera field. In addition, white screens were added behind the participants in order to increase the contrast between individuals and the dark room walls. This contrast enhancement allowed to better visualize the dyad movements within the video clips. Two ROIs were defined in each video: the first one for whole body of participant 1 and the second one for whole body of participant 2 (see Fig. 2, Panel A.1.). The output of MEA software are the motion time series of the ROIs (see Fig. 6).

Data analysis

Synchrony computation

To compute synchrony, we uploaded the MEA output containing the participants' movements to the statistical software Surrogate Synchrony (SUSY) to compute synchrony between the MEA time series. SUSY is written in R (R package: https://wtschacher.github.io/SUSY/[54]). For the present analyses, the web version was used: http://www.embodiment.ch. Movement synchrony for the two ROIs (ROI 1 = participant A; ROI 2 = participant B) was computed separately for each task (i.e., competition, cooperation, and fun) and odor condition (i.e., peppermint odor diffusion and no-odor diffusion).

Synchrony computation in the SUSY software is based on the windowed cross-correlations of the movement time series of both individuals in a given dyad. The parameter settings used in the present study were segment size = 30 s and maximum lag = 3 s. More specifically, dyadic time series were cut into 30 s segments and the cross-correlations were computed within each segment up to a maximum lag of +/− 3 s between time series. All cross-correlations in the window defined by the chosen maximum lag were considered. The average of these cross-correlation values in each segment were gathered over all segments within an experimental condition to determine a unique value of aggregated cross-correlation for a given dyad, in each experimental condition.

The SUSY algorithm transforms the Pearson correlations using Fisher's Z transformation to compute further the mean correlations of a series. This is performed either by using the absolute correlation values or by using the original signed correlation values ranging from − 1 to 1. This differentiation is crucial because any correlation, positive or negative, can be considered as a sign of absolute synchrony (represented by absolute Z values). With the non-absolute signed values, in-phase correlations can be distinguished from anti-phase correlations[55]. In the present analysis, we used signed values of synchrony to reveal the effects of task and odor on the nature of movement synchronization.

Control for random or coincidental synchrony is performed in SUSY by calculating surrogate testing in a second step. This technic also allows for a further control against impacts of higher or lower movement values on the synchrony results. Surrogate time series were created here by randomly shuffling the sequence of segments in a time series of the two individuals that constituted each dyad. Then, cross-correlations were computed on the shuffled data to obtain pseudo-synchrony values. For each time series of a specific dyad and task, Z values of the real dyadic time series were then compared to the surrogate Z values in the multiple shuffled time series by an effect size measure. These effect sizes were the key measures of synchrony that were used in ensuing statistical analyses.

Each condition lasted 5 min and was divided into 30-s segments, resulting in 10 segments per condition, without overlap between windows. In addition, all available lags were used to calculate the cross-correlations in the time series. As the maximum lag used by SUSY was 3 s, and on the sampling rate of the movement time series was 30 Hz, there were 120 cross-correlation values in each +/− 3 s window.

Statistical analysis

Our first hypothesis concerns the effect of odors on the affective states. We hypothesized that diffusing peppermint odor in the room will make the participants feel more aroused and pleased (H1). The second hypothesis refers to the effect of the task on the affective states. The fun task should enhance the perceived valence and arousal compared to the competition and cooperation tasks (H2). The third hypothesis states that the participants will move more in the odor condition than in the no-odor condition (H3). To examine H1 and H2, and H3 a two-way repeated-measures analysis of variance (RM ANOVA) (Odor [Yes, No] × Task [Competition, Cooperation, Fun]) was applied on the perceived valence, the perceived arousal and the sum of movement. For the repeated-measures ANOVA (H1, H2 and H3), we conducted Bonferroni-corrected pairwise comparisons to control for multiple comparisons.

Our two last hypotheses reflect the effects of odor and task on movement synchrony. We hypothesized that diffusing a peppermint odor in the environment will increase movement synchrony in all three tasks (H4). Following previous published reports, we expected to find more movement synchrony during the fun task than in the cooperation and competition tasks (H5). To examine H4 and H5, we conducted Student t-tests against 0 to reveal the presence or absence of in-phase and anti-phrase synchrony. Then, a mixed-effects model was used with Odor and Task entered as fixed effects. For the mixed-effects model, we used Tukey's post-hoc tests to compare the different task conditions.

The dyad identifier was entered as random effects.

Data analysis for H1, H2, and H3, as well as for the synchrony analyses (H4 and H5), was conducted using SPSS V.30 software. The significance level was set at $p < 0.05$. Normality was checked using the Shapiro–Wilk testPartial eta-square effect sizes are reported alongside each inferential analysis.

Data availability

The materials are shared openly as part of the publication of the article. The statistical data can be obtained on request to Yvonne N. Delevoye-Turrell (yvonne.delevoye@univ-lille.fr), but the raw camera data cannot be shared due to the ethical difficulty of giving open access to non-anonymous video clippings.

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Author contributions

M.R.C. contributed to the conceptualization, design, figures design, data collection and writing of the paper; all four co-authors contributed to the conceptualization, design, and writing of the paper. Y.N.D-T covered in addition for the ethical and financial aspects of the study.

Declarations

Competing interests

The authors declare no competing interests.

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