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The association between synchrony and intellectual productivity in a group discussion : a study using the SenseChair

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In recent years, multi-person meeting formats such as brainstorming sessions and hackathons have become prevalent in numerous workplaces. Despite the introduction of several effective methods and guidelines for these meeting formats, optimal performance is not always attained, even when utilizing such methods and guidelines. There has been active research to support intellectual production activities, and there is a demand to establish a quantitative index to assess the intellectual productivity of a group. In this study, we employed a method for evaluating the intellectual productivity of a group by analyzing the physical movements of conversationalists during discussions. With our main focus on the synchrony of conversationalists, we examined the correlation between synchrony and intellectual productivity and delved further into our analysis, specifically exploring the relationship between pairwise synchrony and various factors such as the number of ideas generated, the number of idea categories, and the originality of ideas produced during a discussion. Our analysis revealed a marginally significant positive correlation between the mean value of pairwise synchrony and the number of ideas generated by the team during the discussion. Our findings indicate that, as more pairs synchronize their body movements during a discussion, a greater number of ideas are generated by the team. Additionally, we suggest that analyzing local pairwise synchrony, focusing on pairs of participants rather than all participants in the discussion could provide further insights into the correlation with the intellectual productivity of the group as a whole.

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Introduction

The generation of concepts, schemes, and other cognitive artifacts through the application of mental faculties is defined as activities of intellectual production, and the efficacy with which these are brought forth is defined as intellectual productivity Dosi et al. (2000). Intellectual productivity is not only achieved by experts but also by ordinary community-based populations Woolley et al. (2010). In recent years, various collaborative meeting methods involving multiple participants, such as meetings, brainstorming sessions, and hackathons, have gained widespread popularity in numerous office settings. These techniques are expected to enhance the collective intellectual productivity of the group through the exchange and chain reaction of innovative ideas amongst peers, thereby fostering creativity and generating fresh insights Osborn (2012). Improving the efficacy of such intellectual production activities is believed to result in reduced working hours and lower labor costs, and ultimately drive the progress of companies and associated societies, underscoring the growing importance of supporting these activities. However, despite the introduction of several effective methods and guidelines, optimal performance is not always achieved in meetings utilizing these approaches. In this regard, there has been a recent surge in the development of systems designed to facilitate intellectual production activities. Still, supporting such activities can be challenging since intellectual productivity itself cannot be quantified numerically, making it difficult to evaluate tangibly Ramírez and Nembhard (2004). Thus, numerous studies aimed at developing indices that are supposed to correlate with intellectual productivity have been conducted Woolley et al. (2010).

In the context of face-to-face interaction including multi-person meetings, interactional or nonverbal synchrony (Henceforth, it will be denoted as NVS.) is commonly observed. This is an unconscious process that occurs during interpersonal communication, whereby interlocutors tend to move at the same time or in a similar rhythm with each other Bernieri and Rosenthal (1991). The degree of NVS varies depending on the content of the conversation, such as cooperative conversations and discussions Bernieri et al. (1996), Paxton and Dale (2013). In addition, this phenomenon has been found to be positively associated with the greater creativity of ideas generated during divergent dyadic conversations Won et al. (2014) as well as the increased level of rapport between the interlocutors Fujiwara et al. (2021). In relation to creativity, NVS has been examined only in dyadic interactions Won et al. (2014). However, if it is linked to the smoothness of interaction, it can also be related to the intellectual productivity of the group.

Given that our participants are seated, as in many meeting settings, and engaged in a 15-minute group discussion to generate ideas, they need time to think and are not expected to always express overt nonverbal behavior such as nodding or hand movements throughout the discussion. In such a situation, seated swaying, an integrated measure of those nonverbal behaviors, as well as other subtle behavioral cues may be a more pronounced measure to represent the group's interaction dynamics. Some emotion-related behaviors such as laughter and exclamation are also expected to be included in body sway. Thus, analyzing the association of the NVS in the seated swaying behavior among the group members and their intellectual productivity may offer theoretically and practically important findings. To obtain data on the seated swaying, we employed SenseChair, an office chair-type sensing device that we have been studying Fujiwara et al. (2019). This device can measure the center of gravity and weight changes of a seated person in real-time and, when utilized in a discussion situation, can non-invasively and non-intrusively acquire the body movements of multiple seated speakers.

Therefore, in this study, we utilized SenseChair to identify the NVS in the seated swaying motion of multiple speakers.

In this paper, we investigated the association between the quantity and quality of ideas and the NVS of teams engaged in divergent conversations for idea generation. The groups consisted of a general, publicly recruited population and did not include professionals involved in intellectual and creative activities (e.g., artists, poets, or professors). In terms of group NVS, we employed two types of measures. The one is a single *global NVS* that should be observed among all members of the team. The measure is straightforward because it treats the group as a single entity, but it could be more restrictive because it requires all group members to move at the same time. The other is pairwise NVS within a team, allowing us to represent the group NVS as an aggregated effect of local NVS. We hypothesized that NVS scores would be positively associated with intellectual productivity. We also explore which, *global NVS* or the aggregated measure of local pairwise NVS, is associated with intellectual productivity more.

Related work

Work for group intellectual production activities. There have been significant advancements in the development of systems that support the intellectual production activities of groups. Doganata et al. created an interface that presents meeting minutes in the form of graphs that are easy to comprehend and extract information from Doganata and Topkara (2011). These graphs represent the relevant objects used or produced during meetings as well as the activities of the individuals in the meeting. The connected graph of meeting materials, participants, and tasks enables quick and structured access to the meeting data. Chandrasegaran et al. also developed TalkTraces, which makes use of speech information and natural language processing techniques to provide a thematic overview of conversations in real-time, thereby enabling participants to easily connect with past and ongoing discussions Chandrasegaran et al. (2019). Such support systems are often designed to automatically summarize the main points of a meeting based on voice and eye information during the meeting and to facilitate access to necessary information. However, despite the benefits of such support systems, it remains difficult to quantify the intellectual productivity of a group of people. There is currently no clear indicator for quantitatively evaluating such productivity, which makes it difficult to evaluate the effectiveness of these support systems.

Hence, significant research has been directed toward the quantitative assessment of the intellectual productivity of a group. Woolley et al. investigated this topic and discovered a latent factor signifying group intelligence based on the observation that groups that excel in one cognitive task often perform equally well in other cognitive tasks Woolley et al. (2010). This factor was found to be related to the social sensitivity of group members, the variability of their statements in discussions, and the proportion of women in the group, thus indicating the possibility of evaluating the intelligence of the group itself. However, utilizing this factor as an indicator for assessing the intellectual productivity of a group is problematic because it necessitates the prior measurement of sensitivity via a test. It is also a prediction that is dependent on the characteristics of the members and cannot consider the substance of the discussions. Given the variation among members, it is desirable for the intellectual productivity assessment index of a group to be able to evaluate not the members of the group but rather their intellectual production activities. Therefore, NVS, which is an indicator based on the bodily movements of the participants, has been garnering attention and will be discussed in the following section.

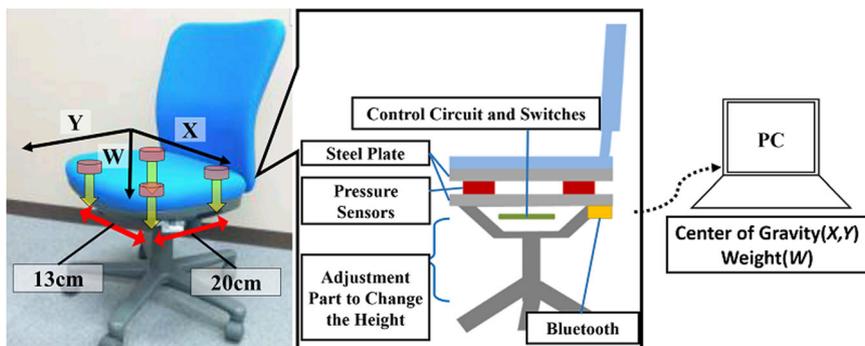


Fig. 1 Configuration of SenseChair and system overview, the left side of the figure shows the arrangement of pressure sensors under the seat surface, and the center and right sides show the outline of the weight data acquisition system.

Work on nonverbal information and conversational situations.

Numerous studies have been conducted to assess conversational situations by detecting nonverbal cues such as volume, gestures, and eye direction in conversational environments using microphones and cameras. Lyndon et al. developed a system that automatically extracts emphasized parts of speech using the speech pitch information of voice information in a study that used microphones Kennedy and Ellis (2003). Wrede et al. proposed a method for detecting conversation excitement from speech Wrede and Shriberg (2003). Thus, microphones can provide detailed information about conversational situations. However, estimating conversational situations in the absence of speech can be challenging, impairing its usefulness in situations where long periods of silence may occur. Otsuka et al. modeled conversational structures such as speakers and listeners by estimating the eye movements of each participant in a group meeting from video images Otsuka et al. (2007). However, camera-based methods also have limitations such as occlusion, blind spots, and labor-intensive installation. Moreover, users may feel uncomfortable about being sensed, which may hinder smooth communication. Therefore, to obtain emergent NVS during discussions, it is desirable to use a fine sensing method in an environment where the user is unaware of the sensor’s presence as much as possible. For this, we propose SenseChair, a chair-type device that can sense the center of gravity and weight on the seat surface without making the user aware of the presence of sensors, using both a posture identification and personal identification method for our study Fujiwara et al. (2019). In this study, we focus on the user’s seat sway among nonverbal information, and obtain and analyze it using SenseChair.

We employ SenseChair in this study to procure the swaying motions of each member seated in a group during discussions and detect bodily NVS from this acquired data. Moreover, we scrutinize the importance of this NVS in determining the intellectual productivity of the discussion by drawing comparisons between it and the quantity and caliber of the ideas generated.

NVS and conversation content. NVS is a phenomenon in interpersonal communication whereby an individual unconsciously attunes to the movements of another person Bernieri and Rosenthal (1991), Condon and Ogston (1966). Won et al. employed Kinect to compute the NVS between participants and found that this NVS, as well as the ideas generated during a discussion, were significantly linked to the content of the conversation Won et al. (2014). Bernieri et al. used a camera to record a multi-person conversation and discovered that the frequency of NVS varied depending on the content of the conversation Bernieri et al. (1996). As explained earlier, many studies have reported the association between the detection of bodily NVS and the content of communication, and the effectiveness of NVS as an indicator of

smooth communication has been demonstrated Bernieri and Rosenthal (1991), Fujiwara et al. (2021). Consequently, in this study, we examine a method to assess the intellectual productivity of a group using bodily NVS in a discussion.

Analysis methods for NVS

The vast majority of studies have demonstrated that NVS is associated with the smooth flow of communication Bernieri and Rosenthal (1991), Fujiwara et al. (2021), but several approaches have been proposed for detecting bodily NVS Delaherche et al. (2012). This paper focuses on users’ bodily movement NVS, which occurs when a user subconsciously synchronizes with their conversation partner’s movements during face-to-face communication, including nodding timing, the frequency NVS of bodily movements, and the similarity of gestures. We examined time-series sway data collected by SenseChair and determined the frequency NVS of bodily movements among interlocutors.

Calculation of center of gravity position using SenseChair.

Figure 1 provides an overview of SenseChair, which is a sensing device in the form of a chair. It is equipped with pressure sensors at the four corners under the seat surface, enabling it to acquire real-time weight and center of gravity position data at up to 100 Hz. Unlike other chair-type devices, this system has fewer sensors, is simpler to implement, and is less expensive to install and deploy. Additionally, it offers the advantage of being flexible enough to be applied to chairs with different shapes and is highly accessible for daily use. The center-of-gravity position comprises the X-coordinate (from the front of the chair to the left and right) and the Y-coordinate (in the frontal direction of the chair). We used a strain gauge-type force pressure sensor manufactured by Minebea. The values of the sensors at the four corners are denoted as Front Left (FL) [kg], Front Right (FR) [kg], Back Left (BL) [kg], and Back Right (BR) [kg]. Furthermore, the distance between the sensors along the X-axis and Y-axis are referred to as Lx [m] and Ly [m], respectively. The coordinates (X, Y) of the center of gravity of the rectangle formed by the four sensors can be obtained from equations (1) and (2).

$$X = \frac{FR \times Lx + BR \times Lx}{FL + FR + BL + BR} \tag{1}$$

$$Y = \frac{FR \times Ly + FL \times Ly}{FL + FR + BL + BR} \tag{2}$$

The coordinate system’s origin is BL and the X-axis’s positive direction corresponds to the right, while the Y-axis’s positive

direction corresponds to the forward direction. The weight W is the summation of the four sensor values and is calculated using the following equation:

$$W = FL + FR + BL + BR. \quad (3)$$

The values derived from equations (1) and (2) are utilized as X [m] and Y [m] to indicate the center of gravity position, while W [kg] denotes the change in weight. The change in weight may be seen as the vertical oscillation of the seated individual.

As the strain gauge force sensor has a rated capacity of 50 kg, each sensor output range is between 0-50 [kg]. Thus, when an adult male sits on the chair, it is necessary to prevent the pressure from being concentrated on a single sensor. This can be achieved by horizontally fixing the sensor and distributing the pressure uniformly to measure the weight of the user on the chair. The signal from the pressure sensor undergoes approximately 300 times amplification after being subjected to noise reduction via a bridge circuit. After the microcontroller on the board performs A/D conversion, the signal is transmitted to a PC through Bluetooth.

Normalization of time series fluctuation data. We used Sense-Chair to capture the center-of-gravity weight fluctuation of the participants at 20 Hz during a discussion. To analyze the frequency of the time-series sway data at short time intervals, we used the time-series amplitude spectrum as the feature value. For each of the six individuals under discussion, we applied a Hanning window as the window function for the time-series sway data, and 256 data were extracted for around 10 seconds and Fourier transformed. By sliding the window function while overlapping the 255 data, we calculated the window function and acquired the data of time-series amplitude spectra ranging from 0 to 10 Hz. In this manner, we obtained time-series amplitude spectra and time-series phase spectra by performing Fourier transforms at short time intervals. The method employed in this study allows for the application of a window function to time-series data and subsequent Fourier transformation, thereby integrating the movement fluctuations of each participant while considering temporal variations. Due to the characteristics of this method, if even a single participant is not in NVS, the value decreases, allowing for a more conservative assessment of NVS phenomena compared to conventional methods. In this paper, we exclusively concentrate on the amplitude spectrum as, even if the time variation of the phase in a particular frequency band is consistent, if the amplitude spectrum is small, the person seated is barely swaying in that frequency band.

Subsequently, the three time-series amplitude spectral data of individual (U) $P_{U,MD}(f, t)$, which includes the center of gravity (X, Y) and weight change (W) on the seat surface obtained through the above method, were normalized in each frequency band. In this context, “MD” denotes the direction of motion, which is represented by the center-of-gravity position (X, Y) and weight change (W). The time-series amplitude spectral data for one individual were normalized by dividing by the maximum amplitude spectral value in the first three minutes of the 15-min task duration. This was carried out to maintain sensitivity to members whose body movements are typically small and to reduce the possibility of excessively large oscillations. The time-series amplitude spectral data $P'_{U,MD}(f, t)$ after the normalization calculation for the seated individual (U) is expressed as follows:

$$P'_{U,MD}(f, t) = P_{U,MD}(f, t) / \max_{t \in T} (P_{U,MD}(f, t)). \quad (4)$$

“T” signifies the normalized interval length, which was previously defined as 180 seconds. By carrying out the normalization calculation for each participant in this manner, we can

account for individual differences in motion magnitude, thus enabling us to compare the results across all users. Subsequently, we generated time-series amplitude spectral data that reflects the rocking motion of each seated individual by extracting the maximum amplitude values in all directions of movement (i.e., X, Y , and W) at each time point. We took this approach because, if either the center-of-gravity position or the weight of a seated individual exhibits a large amplitude spectrum, it can be inferred that the user is experiencing some form of rocking motion. The resulting time-series spectral data, denoted as $\hat{P}_U(f, t)$, pertains to a given individual (U).

$$\hat{P}_U(f, t) = \max(P'_{U,X}(f, t), P'_{U,Y}(f, t), P'_{U,W}(f, t)) \quad (5)$$

Quantifying bodily NVS. Since $\hat{P}_U(f, t)$ represents normalized spectral power for an individual. Then multiplying this across the target interlocutors is supposed to represent the degree to which nonverbal behaviors were co-occurring. The *global NVS* that emerges among N members of the group is calculated as follows:

$$P_{Global}(f, t) = \prod_{k=1}^{N=6} \hat{P}_k(f, t) \quad (6)$$

where $\hat{P}_A(f, t)$ to $\hat{P}_F(f, t)$ represent the time-series spectral data of the respective individuals, and here, N is 6. The *global NVS* value obtained is supposed to be higher only when all six members in a group move at the same time. This conservative measure is expected to have an advantage since we can avoid mistakenly treating a state of long immobility often seen in meetings for intellectual productivity as a case of high NVS.

As for the *pairwise NVS*, taking participants A and B as an example, $P_{pairAB}(f, t)$ is calculated as follows:

$$P_{pairAB}(f, t) = \hat{P}_A(f, t) \times \hat{P}_B(f, t), \quad (7)$$

where $\hat{P}_A(f, t)$ and $\hat{P}_B(f, t)$ represent the time-series spectral data of the respective individuals. The NVS value approaches 1 when both members of a pair move in unison and approaches 0 when no one moves or only one member moves. For every team, we computed the *pairwise NVS* for every possible pair of members. Given that each group consists of six members, there were ${}^6C_2 = 15$ instances of *pairwise NVS* for a group. The mean and variance of the *pairwise NVS* values within a group were used for subsequent analyses.

Also, to take advantage of decomposing the group NVS into 15 *pairwise NVS* values, we explored in depth how *pairwise NVS* in the groups was associated with intellectual productivity. Specifically, we ordered the *pairwise NVS* values from highest to lowest and then examined how each relates to the task performance.

Experimental data

In this paper, we analyzed the NVS of interlocutors based on their body movements during an alternative-use task involving divergent discussions using data from a conversation experiment Matsui et al. (2019). Figure 2 depicts the experimental environment, which involved 13 groups of six male participants in their 20s to 40s (90 participants in total) who were recruited through a temporary staffing agency. The average age of the experimental participants was 25.5 years, with a standard deviation of 7.1 years. Also, they were strangers to each other and met for the first time in the experiment. Considering that people are known to be more interested in impressions of the opposite sex than in impressions of the same sex O'Leary et al. (1994) and it has been observed that women tend to exhibit greater synchronization than men Fujiwara et al. (2019), we restricted the participants to men in the experiment so that they could concentrate on the task. The

participants were asked to sit on a chair with an initialized SenseChair and then heard an overview of the experiment. They were informed that the center of gravity and weight would be measured using the SenseChair and that they would be recorded. Recording began after the participants filled out the consent form. The experiment's procedure was as follows: Six participants were seated in SenseChairs with three of the participants facing the other three across a table. After self-introductions, the participants performed an alternative-use task, which involved naming as many "uses for a brick" as possible within 15 minutes. Participants were provided guidelines to ensure a structured yet open discussion. The guidelines consisted of the following three criteria: (1) the selection of one facilitator, who would initiate the discourse, while subsequent interventions by other participants



Fig. 2 Experimental environment.

remained largely unregulated; (2) standing during the discussion was disallowed; and (3) note-taking remained optional. Data collection was facilitated using a 360-degree camera (Kodak PIXPRO SP360 4K) in conjunction with two IC recorders (Sony ICD-TX800).

The task performance as a proxy of intellectual productivity included the number of ideas, number of idea categories, and originality of ideas for each team. The number of ideas and the number of idea categories were counted according to the posterior classification of all teams' ideas by the two experimenters during discussions. The uniqueness of ideas was defined as follows: Ideas submitted by one of 13 teams equaled three points, ideas generated by two of 13 teams equaled two points, ideas from three out of 13 teams equaled one point, and ideas generated by more than four out of 13 teams equaled zero points. The uniqueness scores for each idea calculated in this way were summed within a team to arrive at an idea uniqueness score for that team. We investigated the correlation between the number of ideas, number of idea categories, and idea uniqueness scores calculated for each team in the above manner and the mean and variance values of the paired NVS of the teams.

Results

We obtained one *global NVS* and 15 *pairwise NVS* scores per group, and examples are shown in Fig. 3. Figure 3a shows those of the group exhibiting the highest average *global NVS*, and Fig. 3b shows of the group exhibiting the lowest average *global NVS*. Intriguingly, we discovered that even in regions where *global NVS* exhibited small fluctuations, *pairwise NVS* continued to exhibit a relatively wide range of variations. Moreover, the peaks showed the same trend as that of the entire team. The observed

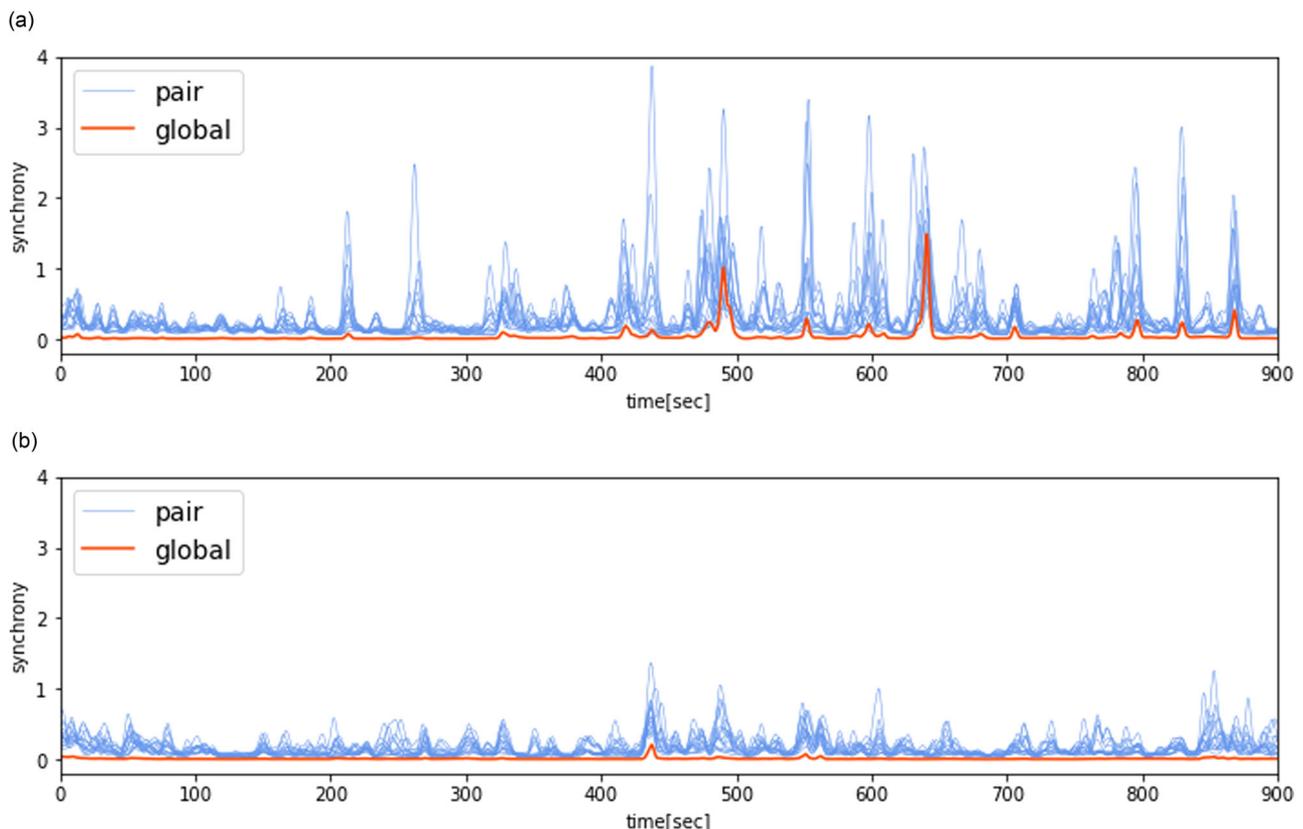


Fig. 3 Examples of the global and pairwise NVS, the blue line in the figure indicates a single pairwise NVS, while the red line represents the global NVS. **a** is for the team with the highest average global NVS, and **b** is for the team with the lowest, respectively.

Table 1 Spearman's rank correlation between *global NVS* and intellectual productivity.

Average of global NVS - Number of ideas	0.377 ($p = 0.204$)
Average of global NVS - Number of idea categories	0.154 ($p = 0.614$)
Average of global NVS - Uniqueness of ideas	0.363 ($p = 0.223$)

Table 2 Spearman's rank correlation between *pairwise NVS* and intellectual productivity.

Average of pairwise NVS - Number of ideas	0.543 ($p = 0.055$)
Average of pairwise NVS - Number of idea categories	0.284 ($p = 0.347$)
Average of pairwise NVS - Uniqueness of ideas	0.374 ($p = 0.208$)
Variance of pairwise NVS - Number of ideas	0.408 ($p = 0.167$)
Variance of pairwise NVS - Number of idea categories	0.452 ($p = 0.121$)
Variance of pairwise NVS - Uniqueness of ideas	0.290 ($p = 0.336$)

correlation coefficient between the global NVS and the pairwise NVS was notably high at 0.945.

Global NVS and intellectual productivity. First, we carried out a Spearman's rank sign test to examine the correlation between the mean of the *global NVS*, which was obtained by averaging NVS in the entire task time, and their corresponding task performance. As depicted in Table 1, the results revealed that no significant correlations between the mean of the *global NVS* and the task performance. This may be because the value of *global NVS* was too small and did not have sufficient variation during the discussion, making it difficult to see differences between groups. When calculating NVS, the value of NVS tends to be lower and more stable as the number of synchronizing individuals increases. Consequently, while the global NVS demonstrates a gradual response, the pair NVS dynamically fluctuates as the discussion progresses. The moment when global NVS peaks correspond to when all participants are in sync, and a similar peak can be anticipated in pair NVS. However, peaks observed in pair NVS may also encompass dynamic responses of individual pairs that might be attenuated in global NVS. Thus, even if the overall and individual pair peaks show the same trend, there is a possibility of misalignment in their timing. Depending on the nature of the task, which peak contributes more can vary, highlighting the importance of closely observing both. We proceeded to investigate the mean and variance of *pairwise NVS* within a group.

Pairwise NVS and intellectual productivity. We took the average of all *pairwise synchronies*, and then did the same with the *global NVS*, averaged them over the entire task time. After that, we computed Spearman's rank correlation between the mean and variance of the *pairwise NVS* and task performance. The result revealed a medium-level positive correlation ($\rho = 0.543$, $p = 0.055$) between the mean of *pairwise NVS* and the number of ideas per team as shown in Table 2), which did not reach the level of significance slightly. It can, therefore, be inferred that an increase in the number of synchronized pairs within a team results in the generation of more ideas. To further validate the results of our study, we conducted a reanalysis using the following procedure:

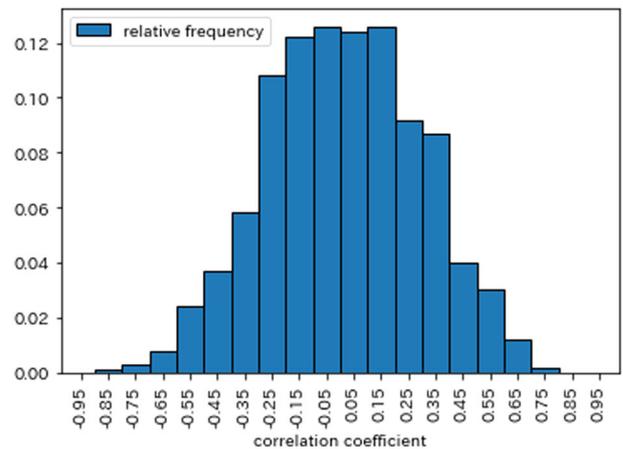


Fig. 4 The distribution of the correlation coefficients obtained from the 1000 reanalyze.

1. The data of all participants was randomly shuffled to form 13 pseudo teams, different from the original team compositions.
2. For each pseudo team, the average pair NVS was calculated, and its correlation with the idea count of the original teams was determined using Spearman's rank correlation coefficient.
3. Steps 1 and 2 were repeated 1000 times.

The distribution of the correlation coefficients obtained from the 1000 reanalyses is shown in Fig. 4.

From this analysis, it was confirmed that the probability of observing correlation coefficient of 0.543, as identified in our initial analysis, between the idea count and average pair NVS, is less than or equal to 0.044. This suggests that the correlation identified in our initial analysis is indeed based on the actual interactions among members.

The order of pairwise NVS within a group and intellectual productivity. To further evaluate the importance of *pairwise NVS* within each team, we sorted the 15 pairs by *pairwise NVS* scores to determine which NVS scores were more related to task performance: pairs with high NVS or pairs with low NVS. For each rank of the NVS score in the groups, we calculated the correlation to the task performance. The result is illustrated in Fig. 5. The findings of our analysis suggest that the *pairwise NVS* of the top-ranked pairs within the teams may exhibit a negative correlation with the uniqueness of ideas among the teams. Thus, when the maximum value of *pairwise NVS* is excessively high, the originality of the team's idea may diminish. Moreover, the results imply that teams with low NVS tend to have a weak positive correlation between the number of ideas generated among the teams and the *pairwise NVS* value. Consequently, it is plausible that teams with a higher minimum threshold of *pairwise NVS* within a team produce more ideas.

Discussion

The analysis has revealed a marginally significant positive correlation between the mean value of *pairwise NVS* and the number of ideas generated during the task, indicating that more synchronized body movements among pairs within a team lead to greater productivity in generating ideas. Furthermore, the analysis presented in Sections "Global NVS and IntellectualProductivity" and "Pairwise NVS and IntellectualProductivity" indicate that the positive correlation with task performance is stronger for *pairwise NVS* than for the *global NVS*. This finding suggests that more idea

Correlation Coefficient Difference in Team Isotopic Pairs

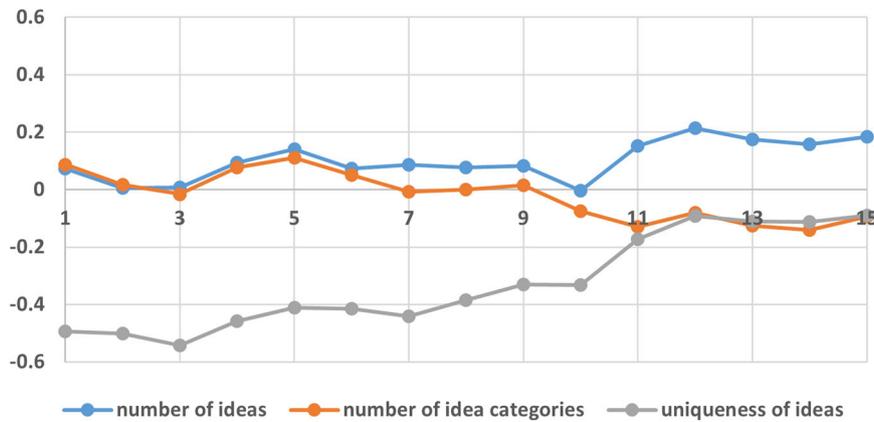


Fig. 5 The abscissa indicates clusters of pairs arranged in ascending order of pair synchronicity within a team, whereas the ordinate represents the correlation coefficient. For each rank, the correlation coefficient was derived from the pairwise NVS values and the team’s task performance.

generation occurs during discussions when pairs synchronize their body movements frequently. A prior study Matsui et al. (2019) has reported no connection between the NVS of all participants in a discussion and their task performance.

As shown in Section “Global NVS and IntellectualProductivity”, the *global NVS* is less variable than the *pairwise NVS*, and it is conceivable that the more people calculate NVS, the greater the weakening effect on each other. Although it is possible that there may be a more suitable number of people to calculate the NVS further than the *pairwise NVS* for pairs of two people, these results indicate that exploring NVS within a discussion team, focusing on pairs in particular, could expose new characteristics and correlations with intellectual productivity that were not previously noticed in the NVS of all participants in the discussion. In this study, we concentrated our analysis on “pairs,” positing them as the fundamental unit for synchronization within a compact, non-stationary six-member group. However, contingent on the participant count and the nature of the discussed topics, synchronization could potentially manifest within clusters encompassing three or more members Nathe et al. (2022), Pecora et al. (2014). Moreover, the temporal dynamics of the emergence, consolidation, and cessation of such synchronizations remain unexamined. Investigating the interrelation between these dynamics and intellectual productivity offers a promising avenue for future research.

Moreover, the intra-team analysis presented in Section “The Order of Pairwise NVS within a Group and IntellectualProductivity” demonstrates that pairs with high and low *pairwise NVS* values in each team exhibit distinct tendencies. Specifically, for each team, high *pairwise NVS* values were found to be negatively correlated with the originality of ideas for that team, while low *pairwise NVS* values showed a weak positive correlation with the number of ideas generated. In the case of the former, pairs with particularly high *pairwise NVS* values are believed to be those in which both participants perform large actions, such as laughing at the same time, or in which the members are not focusing on the discussion and are frequently moving their bodies. As a result, such members who are not actively engaged in productive discussions are deemed to be a factor that reduces the originality of ideas. In the latter case, the higher the lower limit of *pairwise NVS* within a team, the more frequently the members synchronize with each other, and these NVS instances may be linked to the active expression of opinions. Therefore, it is plausible that there is a specific range of *pairwise NVS* values for groups with high intellectual productivity. By examining *pairwise*

NVS for each pair individually, it may be possible to identify the traits of groups with high or low intellectual productivity.

In consideration of future prospects, we plan to continue our analysis of the correlation between NVS and intellectual productivity, with a particular focus on pair NVS as discussed above. It should be noted that the current analysis was an average evaluation of the entire task time, and therefore it is important to investigate the relationship between NVS and intellectual productivity during different phases of the task, such as the early, middle, and end phases, or after ideas have been generated. Due to the small sample size of teams used in this study, significant results were not obtained. Thus, conducting further experiments with a larger number of teams is necessary for more reliable results. Moreover, the evaluation of the quality of ideas in this analysis was evaluated by the number of overlaps of ideas with other teams. Given that the quality of ideas varies depending on the individual and the purpose, it is important to establish more universal criteria for evaluating idea quality and conduct statistical analyses with larger numbers of evaluators. By doing so, we hope to gain a better understanding of the relationship between NVS and intellectual productivity, and to develop a method for evaluating the intellectual productivity of a group based on NVS. While the design of the task permitted uninhibited verbal participation by all individuals, the inherent characteristics of leaders and their roles might exhibit variations in typical office discussions. The discrepancies in synchronization patterns stemming from individual traits present intriguing avenues for exploration. As our research progresses, our objective is to develop an evaluative model accounting for these individual characteristics, and to refine analytical methodologies by aggregating data across diverse tasks and participant profiles. Furthermore, utilizing questionnaires to comprehensively understand the participants’ personality and characteristics, and analyzing their relationship with NVS, is a promising direction for future research.

In this study, we specifically analyzed NVS in seated oscillations. However, by adopting different experimental settings and incorporating data from cameras and other sensors, it is postulated that the research can be expanded from the perspective of intellectual productivity. Specifically, we are examining evaluation metrics focused on nodding actions, which are frequently observed as cooperative behaviors during communication. By integrating the findings from these research areas, there is a potential to gain new insights. Moving forward, we plan to pursue our research considering such expanded studies.

Conclusion

In this paper, we presented a method to evaluate the intellectual productivity of a group based on the physical movements of the participants during discussion with a focus on their NVS and analyzed the correlation between NVS and intellectual productivity. We scrutinized the correlation between *pairwise NVS* and the number of ideas generated, the number of categories into which ideas fall, and the originality of ideas put forward during the discussion. Our analysis revealed a marginally significant positive correlation between the mean value of *pairwise NVS* and the number of ideas produced by the team during the discussion. We discovered that the more pairs that synchronized their body movements during the discussion, the greater the number of ideas generated by the team. We suggest that the correlation with the intellectual productivity of the group as a whole could be better explained by analyzing the local *pairwise NVS*, focusing not on all participants in the discussion but rather on pairs of participants. Note that while the conclusion is primarily based on the marginally significant correlation result, the subsequent analysis with the random shuffling technique provided additional support to the association between the idea count and average *pairwise NVS*. Nevertheless, to obtain more reliable results, it is necessary to collect and analyze data from larger-scale experiments.

Looking ahead, we plan to further explore the relationship between *pairwise NVS* and group intellectual productivity. Specifically, we aim to clarify the changes over time in *pairwise NVS* and intellectual productivity, as well as the relationship between the quality of ideas and various elements of NVS, with the goal of developing a method to evaluate the intellectual productivity of a group based on NVS.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

YI provided the conception and design of the study. MM analyzed the data, interpreted the results, and wrote the draft of the manuscript. YI, KF, and KI revised the manuscript critically for important intellectual content. All authors contributed to discussions.

Competing interests

The authors declare no competing interests.

Ethical approval

Our experiments were carried out according to the principles expressed in the Declaration of Helsinki and approved by Research Ethics Committee, Graduate School of Information Science and Technology, Osaka University.

Informed consent

All participants provided written informed consent to join the study, and this consent was also approved by the ethical committee.

Additional information

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