Nonverbal Synchrony of Facial Movements and Expressions Predict Therapeutic Alliance During a Structured Psychotherapeutic Interview

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Abstract

Nonverbal synchrony (NVS) of a patient's and therapist's body parts during a therapy session has been linked with therapeutic alliance. However, the link between NVS of face parts with therapeutic alliance remains unclear. The clarification of this link is important in understanding NVS. Accordingly, we used a video imaging technique to provide quantitative evidence of this link. The 55 participants in this study were the same as in a previous study. Both the participants' and the therapist's faces were video recorded during structured psychotherapeutic interviews. Our machine quantified 500,500 participants' faces and 500,500 therapists' faces from the perspectives of facial movements and expressions. Results show that absolute synchrony of happy and scared expressions were positively related to therapeutic alliance. However, symmetrical synchrony of left eye movements negatively predicted therapeutic alliance, although participants' sex, age, volume of facial movements, and volume of facial expressions were controlled. Absolute synchrony of facial expressions was regarded as emotional interaction within 2 seconds delay, whereas symmetrical synchrony of left eye movements was regarded as a blocker of emotional interaction.

Keywords: nonverbal synchrony, facial movement, facial expression, video imaging technique, structured psychotherapeutic interview, symmetrical communication pattern

Title

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Introduction

Humans synchronize nonverbally with others during interactions (Repp & Su, 2013) in terms of posture, facial movements (Semin & Cacioppo, 2008), and even breathing patterns (McFarland, 2001). This is referred to as nonverbal synchrony (NVS; Condon & Ogston, 1966). Many studies have found that NVS can strengthen collaborative relationships between two adults (Chartrand & Lakin, 2013). Recent studies have measured NVS precisely within a short time without a human rater's bias (Bernieri, Davis, Rosenthal, & Knee, 1994) through video imaging techniques (Ramseyer & Tschacher, 2011; Schmidt, Morr, Fitzpatrick, & Richardson, 2012) and have enabled clarification of the link between NVS of body/head parts and collaborative relationships (Won, Bailenson, Stathatos, & Dai, 2014). However, such studies have primarily focused on body/head parts; the link between NVS of face parts and collaborative relationships remains unclear, even though an electromyography study established the link between NVS of face parts and willingness for future interaction (Riehle & Lincoln, 2018). Clarification of this link through a video image method is important to fully understand NVS and contribute to the understanding of nonverbal behavior in dyadic relationships (Riehle, Kempkensteffen, & Lincoln, 2017; Schmidt et al., 2012; Won et al., 2014). Accordingly, our study clarified the link between NVS of face parts and collaborative relationship during structured psychotherapeutic interviews.

Nonverbal Synchrony and Collaborative Relationship

On the basis of social cognition theory (Semin & Cacioppo, 2008), our rationale was that one's NVS with the other encourages perceived social unity and a collaborative relationship with the other. Indeed, a study found that people who watched and experienced a stranger's nonverbal behavior synchronously reported social unity with the stranger and perceived physical and personal resemblance to the stranger more strongly than those who experienced asynchronous nonverbal behavior (Paladino, Mazzurega, Pavani, & Schubert, 2010). An empirical review indicated that NVS between two persons is linked with liking, empathy, and a feeling of closeness (Chartrand & Lakin, 2013). Meta-analysis of NVS also supported the link between NVS and collaborative relationships (Vicaria & Dickens, 2016).

The link between NVS and collaborative relationships was confirmed in community settings (Chartrand & Bargh, 1999). NVS is positively linked with social unity (Miles, Lumsden, Richardson, & Neil Macrae, 2011), self-disclosure (Vacharkulksemsuk & Fredrickson, 2012), and collaborative intentions, regardless of whether the intentions are conscious (Shockley, Santana, & Fowler, 2003) or unconscious (Lakin & Chartrand, 2003). High school teachers who perceive a collaborative relationship with their students show more NVS than those without such a relationship (Bernieri, 1988). Adults who feel positive affect during a conversation with a stranger also show NVS with the stranger more frequently than those who do not feel positive affect (Tschacher, Rees, & Ramseyer, 2014). These findings validate the link between NVS and collaborative relationships in a community setting.

The link between NVS and collaborative relationships was also found in clinical settings (Riehle & Lincoln, 2018), although the collaborative relationship in clinical settings was referred to as therapeutic alliance (Martin, Garske, & Katherine, 2000). One study analyzed 70 outpatients who took part in approximately 40 psychotherapy sessions per patient and found that NVS between the patients and their therapists during the sessions was positively linked with their therapeutic alliance (Ramseyer & Tschacher, 2011). Outpatients whose conditions improved during psychotherapy sessions also showed higher NVS with their therapists than those who dropped out during the sessions (Paulick et al., 2017). A review of NVS in clinical fields suggested NVS between therapist and client as a marker of therapeutic alliance (Tschacher & Pfammatter, 2016), with several exceptions (Kupper, Ramseyer, Hoffmann, & Tschacher, 2015; Lavelle, Healey, & McCabe, 2013; Paulick et al., 2018).

The link between NVS and therapeutic alliance has been corroborated (Paulick et al., 2017; Ramseyer & Tschacher, 2011; Tschacher & Pfammatter, 2016); however, a previous NVS study that used a video imaging technique mainly focused on body parts, movement perspective, and total volume of synchrony (absolute value of synchrony). In other words, the NVS studies that use video imaging techniques rarely report face parts, expression perspective, and direction of synchrony (positive or negative value of synchrony), even though many studies indicated the importance of these parts, perspective, and direction (Ekman, 2003; Riehle et al., 2017; Riehle & Lincoln, 2018). Hence, the current study formulated research questions and hypotheses with this regard. Exploration of these research questions contributed to the body of knowledge by extending NVS location (face), meaning (emotional expression), and index (symmetrical or complementary) (Kupper et al., 2015; Paulick et al., 2018; Ramseyer & Tschacher, 2011, 2014; Tschacher et al., 2014).

Nonverbal Synchrony of Facial Movements and Therapeutic Alliance

Previous NVS studies through video imaging techniques (Ramseyer & Tschacher, 2011) primarily focused on the body/head area (Kupper et al., 2015; Paulick et al., 2017; Tschacher et al., 2014); as such, it is unclear whether NVS of face parts is linked with therapeutic alliance. Our study defined facial movements as physical movements of face parts (e.g., eye movements) without any emotional message conveyed by the movements (Ekman & Friesen, 1976). Hence, NVS of facial movements indicates synchrony of the physical movements between two persons. NVS of facial movements was a hot topic in an NVS study (Riehle et al., 2017; Riehle & Lincoln, 2018). Hence, our first research question is, “Is NVS of facial movements linked with therapeutic alliance?”(RQ1) One study using a video imaging technique found that synchrony of head movements was positively correlated with therapeutic alliance, although the correlation did not reach a significant level (Ramseyer & Tschacher, 2014). Facial movements are key components of nonverbal behavior (Ekman, 2003). Hence, it is possible that NVS of facial movements could show correlations similar to the NVS of other areas, such as head and body movements. Hence, we hypothesized that NVS of facial movements would be positively correlated with therapeutic alliance (Hypothesis 1).

Facial Movements and Facial Expressions

The previous NVS studies that used video imaging techniques encoded movements only (Kupper et al., 2015; Paulick et al., 2018), with one exception (Lozza et al., 2018), so that emotional messages conveyed through the movements were still unclear. We defined facial expressions as emotional messages conveyed through facial movements, such as a happy message through one's smile (Ekman, 1993). Hence, NVS of facial expressions indicates synchrony of emotional messages between two persons. A previous study suggested that a specific emotional message can be interpretable from specific muscle movements (Riehle et al., 2017). Actually, occurrences of specific facial movements indicate the occurrence of a specific emotional message (Ekman, 2003). Still, the occurrences of facial movements and emotional messages were measured through a discrete variable (e.g., 0 or 1) but not a continuous variable (e.g., 0 to 1). Our second research question is, "Are continuous movements of face parts linked with continuous emotional messages of the face?" Eye movements have previously been linked to negative emotional expressions (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001); for instance, widened and narrowed eyes are considered to represent fear and disgust, respectively (Lee, Mirza, Flanagan, & Anderson, 2014). Another study also shows the link between eye movements and negative emotions, such as confusion and frustration (D'Mello, Picard, & Graesser, 2007). Hence, we hypothesized that eye movements could be correlated with negative emotional expression (Hypothesis 2).

Complementary and Symmetrical Synchrony

Previous NVS studies focused on absolute values of synchrony (Kupper et al., 2015; Paulick et al., 2017; Ramseyer & Tschacher, 2011; Tschacher et al., 2014), whereas they did not differentiate the direction (positive and negative values) of synchrony. A positive value of synchrony consists of a symmetrical synchrony (Watzlawick, Bavelas, & Jackson, 2011), in which one sends a message and the recipient returns the same message. In case of facial movement, when one's amplitude of facial movement reaches a crescendo, the other's amplitude of facial movement also reaches a crescendo. In case of a facial expression, when one smiles strongly, the other also smiles strongly. Contrary to symmetrical synchrony, a negative value of synchrony consists of a complementary synchrony, in which one sends a message and the recipient returns another message (Watzlawick et al., 2011). In case of facial movements, when one's amplitude of facial movement reaches a crescendo, the other's amplitude of facial movement falls to a minimum. In case of facial expressions, when one smiles strongly, the other displays anger strongly.

Many studies have evaluated these directions of synchrony and reported their different functions in the psychotherapeutic field (Erchul et al., 1999; Fraser, Vachon, Hassan, & Parent, 2016; Rogers & Farace, 1975) but not yet in the NVS field. Hence, our third research question is, “Are complementary and symmetrical synchrony of the face linked differently with therapeutic alliance?” A previous study found positive effects of complementary synchrony on collaborative relationships and negative effects of symmetrical synchrony (Rogers & Farace, 1975). For example, a complementary synchrony of leadership, where one takes leadership and the other takes followership, is linked with a collaborative relationship (Erchul et al., 1999). In contrast, a symmetrical synchrony of leadership, where both people take leadership, is linked with a conflict relationship. These findings were also corroborated in couple relationships (Escudero, Rogers, & Gutierrez, 1997) and therapeutic relationships (Heatherington & Friedlander, 1990). Complementary and symmetrical synchronies are observable in any communication (Watzlawick et al., 2011); consequently, we hypothesized that the symmetrical synchrony of facial movements would be negatively correlated with therapeutic alliance, whereas complementary synchrony of facial movements would be positively correlated with therapeutic alliance (Hypothesis 3A). Similarly, we hypothesized that the symmetrical synchrony of facial expressions would be negatively correlated with therapeutic alliance, whereas complementary synchrony of facial expression would be positively correlated with therapeutic alliance (Hypothesis 3B).

Prediction of Therapeutic Alliance through Nonverbal Synchrony of Facial Movements and Facial Expressions

Most NVS analyses of movements (Kupper et al., 2015; Paulick et al., 2017; Ramseyer & Tschacher, 2011; Tschacher et al., 2014) and expressions (Riehle et al., 2017; Riehle & Lincoln, 2018) were carried out separately; almost none were performed together. Hence, the effects of facial movements and expressions on therapeutic alliance were unclear. The fourth research question is, "Do NVS of facial movements and expressions predict therapeutic alliance?" To avoid multicollinearity (Graham, 2003), we selected eye movements from facial movements because eye movements were the representative of facial movements (Baron-Cohen et al., 2001; Lee et al., 2014). Similarly, we selected happy and scared expressions from facial expressions because the happy and scared expressions were also the representatives of facial expressions (Ekman, 2003; Riehle & Lincoln, 2018). Further, participants' age, sex, the volume of facial expressions, and the volume of facial movements were controlled because they might affect therapeutic alliance (Elvins & Green, 2008; Martin et al., 2000). We hypothesized that NVS of facial movements and expressions would predict therapeutic alliance even after participants' age, sex, the volume of facial expressions, and the volume of facial movements were controlled (Hypothesis 4).

Aims

Before testing these hypotheses, we inspected whether genuine synchrony [synchrony between real pairs] of facial movements and expressions is different from pseudo synchrony [synchrony between random pairs] of facial movements and expressions (Gatewood & Rosenwein, 1981). Similar to a previous study (Ramseyer & Tschacher, 2014; Riehle et al., 2017), we hypothesized that synchrony of facial movements and expressions for the genuine pair would be different from the synchrony of the pseudo pair (Hypothesis 0). The current study aims to test these hypotheses.

To evaluate participants' facial movements, we used dlib (King, 2009) and OpenCV (Bradski & Kaehler, 2000) as the program packages because they have been used in clinical settings and are well validated (Yokotani, Takagi, & Wakashima, 2018). To evaluate participants' facial expressions, we utilized a convolutional neural network model for an emotion recognition task (Arriaga, Valdenegro-Toro, & Plöger, 2017). The convolutional neural network model was common for detection tasks of the human face and human emotion (Levi & Hassner, 2015; Matsugu, Mori, Mitari, & Kaneda, 2003).

Methods

Participants

The present participants were the same as those in a previously published study (Yokotani et al., 2018); however, the sampling of video images and analysis methods were different. The 57 Japanese university students were recruited by asking a university professor to make an announcement during a psychology class, and through snowball sampling that involved identifying students' friends through referrals. Of the 57 students, two were excluded because one refused to participate and the other did not work at our laboratory; consequently, our final sample comprised 55 students. All of the participants provided written informed consent and received a gift card (1,500 Japanese yen, around 12 Euro) in return for their participation. They received no prior information regarding our research questions.

Of the 55 students, 30 were female and 25 were male, and their average age was 22.92 years (*S.D.* 2.82). All participants were native Japanese speakers and were not regular patients at mental hospitals or counseling centers. A male Japanese clinical psychologist with a doctorate degree in philosophy conducted the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision Axis I disorders, Non-patient Edition (First, Spitzer, Gibbon, & Williams, 1997), using the Japanese version (First et al., 2010). The psychologist had over 10 years' experience in the mental health field and had conducted psychological treatment sessions for the inmates of a Japanese prison, as well as mental evaluations for the accused in a Japanese court (Yokotani & Tamura, 2015, 2016). The participants' mean score for global assessment of functioning was 70.25 (*S.D.* 7.98); hence, the majority of participants belonged to a non-clinical sample (Aas, 2011).

Questionnaires

A previous study recommended assessment of therapeutic alliance using participants' responses on a self-report questionnaire (Elvins & Green, 2008). As such, we used a self-report questionnaire to assess therapeutic alliance (Kakii, 1997). The questionnaire consisted of two items (1. I felt that the counselor created a warm atmosphere; 2. I felt familiarity with the counselor) that were rated using a five-point scale (1 to 5). Participants were asked to respond to this questionnaire, after they had completed the interviews. The average score of the two items was 4.44 (S.D. 0.63). To validate the questionnaire, participants also answered an additional four-item questionnaire using the five-point scale. The first two questions pertained to transmission of information (e.g., item 1: I felt that what I wanted to say was transmitted to the counselor) and the last two questions pertained to transmission of emotion (e.g., item 4: I felt that the counselor understood my feelings). The therapeutic alliance scores were positively correlated with transmission of information (r = .444, p < .001) and transmission of emotion (r = .502, p < .001), respectively.

Sampling of video images for facial movements

Participants were interviewed by the clinical psychologist in an experimental room (Fig. 1A). During the interview, both the participants' and the therapist's facial movements were video recorded. All videos recorded during the conversation (1280 × 720 pixels, 29.9 frames per second) were converted into a series of pictures that represented one image for every 100 milliseconds of video (Fig. 1B-1: therapist's face). Participants' and therapist’s head movements change the face coordinates, regardless of actual facial movements (Fig.2). To minimize the effects of their head movements on their facial movements, we used an affine formula (Fig.2). All faces were transformed to one averaged female face image (530 × 530 pixels) (Langlois & Roggman, 1990) (Fig.1B-2, B-3). To determine facial landmarks of the transformed faces, we used OpenCV and dlib (King, 2009), which identified 68 landmarks for each picture (Fig.1B-4). Fig. 3 indicates actual ranges of numbers that cover specific facial parts. The number of participants’ pictures was 1,258,716. For some pictures (5.99 %), we were unable to detect their facial landmarks perfectly because the landmarks were sometimes covered during conversation. The missing facial landmarks in these pictures were estimated using a multiple imputation method (Sterne et al., 2009). The therapist’s missing facial landmarks were estimated in the same manner.

A previous NVS study regarding body movements utilized the first 900 seconds of interviews (Paulick et al., 2017; Ramseyer & Tschacher, 2011; Tschacher et al., 2014). To be similar to these studies, we used the first 910 seconds of interviews. Further, a previous NVS study regarding facial expressions recommended a 7-second frame as a time window size (Riehle et al., 2017). Hence, we divided the interview into 7-second portions; a portion involves 70 faces. The final dataset consisted of participants’ 7150 seven-second portions involving their 500,500 face images and their therapist’s 7150 seven-second portions involving his 500,500 face images.

Quantification of facial movements

We calculated absolute differences in facial landmarks between each picture and a previous picture (i.e., the picture that was taken 100 milliseconds prior to the current one). When the landmarks between the two pictures differed along the X axis, we scored the difference as horizontal movement. $X_{k,n}$ is the x coordinate at time *n* at position *k*; K indicates all positions in specific areas. For the right eyebrow, K contains positions from 18 to 22 (Fig.3). Similarly, when the landmarks differed along the Y axis, we scored the difference as vertical movement. The average of horizontal and vertical movements was regarded as the movement of a specific area. High movement scores indicated a high frequency and wide variety of movements.

$$\mathrm{m}[\mathrm{n}] = \frac{1}{2|K|}\left(\sum_{k\in K}|X_{k,n+1} - X_{k,n}| + |Y_{k,n+1} - Y_{k,n}|\right)$$

The averages of these movements during the first 910 seconds of interviews were also used as an average facial movement score during a session.

$$\bar{m} = \frac{1}{2|K|}\cdot\frac{1}{N-1}\left(\sum_{n\in N-1}\sum_{k\in K}|X_{k,n+1} - X_{k,n}| + |Y_{k,n+1} - Y_{k,n}|\right)$$

N indicates the total number of pictures in a session (9,100). Hence, the average facial movement scores were constant during the session. Fig. 1C shows pairs of one participant’s facial movements and the therapist’s facial movements for 200 frames (20 seconds). Fig. 1D compares a participant's ($m_{par}[n]$) and the therapist's ($m_{th}[n]$) left eye movements for the same 200 frames.

Quantification of Complementary, Symmetrical, and Absolute synchrony for Facial Movements

Cross-correlation coefficients between the participants' and therapist's facial movements were computed using the following formula:

$$\varphi_{par,th}[j] = \{m_{par}[n - \min(j,0)] - \overline{m_{par}}\}\{m_{th}[n + \max(j,0)] - \overline{m_{th}}\}$$

$m_{par}[n]$ and $m_{th}[n]$ represent the participant's and therapist's facial movements at time *n*. $\overline{m_{par}}$ and $\overline{m_{th}}$ are the averages of the facial movements. *j* represents time lags between the participant and therapist, which ranged from -20 to +20 frames (one frame is 100 milliseconds) as recommended by previous studies (Riehle et al., 2017; Riehle & Lincoln, 2018). Negative *j* values indicate that the participant's facial movements occurred after *j* frames of the therapist's facial movements. Positive *j* values indicate that the therapist's facial movements occurred after *j* frames of the participant's facial movements. In short, negative and positive *j* values indicate a delayed response by the participant and therapist, respectively.

To distill symmetrical, complementary, and absolute synchrony, we utilized the following formula:

$$\mathrm{sym}[j] = \sum_{n=1}^{M-1-|j|} \max(0, \varphi_{par,th}[j])$$

$$\mathrm{comp}[j] = -\sum_{n=1}^{\mathrm{M}-1-|j|} \min(0, \varphi_{par,th}[j])$$

$$\mathrm{abs}[j] = \sum_{n=1}^{\mathrm{M}-1-|j|} |\varphi_{par,th}[j]|$$

$$self_{par}[j] = \sum_{n=1}^{\mathrm{M}-1-|j|} \{m_{par}[n - \min(j,0)] - \overline{m_{par}}\}^2$$

$$self_{th}[j] = \sum_{n=1}^{\mathrm{M}-1-|j|} \{m_{th}[n + \max(t,0)] - \overline{m_{th}}\}^2$$

M is the total number of pictures within a seven-second interval (70). Sym[*j*] includes only positive values of $\varphi_{par,th}[j]$, whereas comp[*j*] includes only negative values of $\varphi_{par,th}[j]$. Abs[j] include all $\varphi_{par,th}[j]$ as absolute values (Ramseyer & Tschacher, 2011). $self_{par}[j]$ and $self_{th}[j]$ were variances of the participants' and therapist's movements at *t* time lag, respectively.

The cross-correlation coefficients were also normalized (Yoo & Han, 2009) and these values were referred to as SYM, COMP, and ABS synchrony, respectively. The formula used is more accurate than a previously reported one (Boker, Xu, Rotondo, & King, 2002) because the denominator is adjusted by the time lag.[1]

$$\mathrm{SYM}_{par,th}[j] = \frac{sym[j]}{\sqrt{self_{th}[j]}\sqrt{self_{par}[j]}}$$

[1]Previous formula in SYM is $\mathrm{SYM}_{par,th}[j] = \frac{sym[j]}{\sqrt{self_{th}[0]}\sqrt{self_{par}[0]}}$

$$\mathrm{COMP}_{par,th}[j] = \frac{comp[j]}{\sqrt{self_{th}[j]}\sqrt{self_{par}[j]}}$$

$$\mathrm{ABS}_{par,th}[j] = \frac{abs[j]}{\sqrt{self_{th}[j]}\sqrt{self_{par}[j]}}$$

Fig. 4A shows $\mathrm{SYM}[j]$ of left eye movements between a participant and the therapist during a session. Fig. 4B shows $\mathrm{COMP}_{par,th}[j]$ of left eye movements between a participant and the therapist during a session. The vertical line indicates the duration of the session (one unit is 7 seconds). The horizontal line indicates time lags [*j*]. Negative *j* indicates that the participant synchronized after *j* frames of the therapist's facial movements. Similarly, positive *j* indicates that the therapist synchronized after *j* frames of the participant's facial movements. Their average was regarded as an indicator of genuine synchrony during the session (Fig. 4A, 4B, bold scores). Unlike a prior study, we did not use Fisher's Z-transformation (Ramseyer & Tschacher, 2011) because the synchrony values might exhibit a multimodal distribution[2].

Sampling of video images for facial expressions

The number of pictures for participants' facial expression was the same as the number of pictures for facial movements (N = 1,258,716). Still, in some participants' pictures (6.49%), we were unable to identify their facial expressions. These pictures were discarded. The missing facial expressions in these pictures were estimated using a

[2] Fisher's Z-transformation assumes a unimodal distribution

multiple imputation method (Sterne et al., 2009). The therapist's missing facial expressions were estimated in the same manner.

Quantification of facial expressions

To quantify facial expressions, we utilized an emotion recognition model (Arriaga et al., 2017). The model consists of a fully-convolutional neural network and involves around 60, 000 parameters. The model learned the parameters through 28,709 gray faces with 7 emotion categories (Happy, Scared, Angry, Disgust, Sad, Surprised, and Neutral) (Carrier, Courville, Goodfellow, Mirza, & Bengio, 2013). After 102 epochs training (one epoch involves 28,709 faces), the model predicted 7 emotions of a new data set (3,589 faces) at 66 percent accuracy. Fig. 5 shows examples of three faces and estimated probabilities of emotional expressions on these faces (A-1, A-2, A-3, B). A high probability of a specific emotional expression indicates that the face expresses emotions strongly: for instance, a baby's smiling face (Fig.5 A-1) indicates 97.034 % of happiness (Fig.5 B) meaning the baby strongly expressed happy emotions at the moment the picture was taken.

We applied this emotional recognition machine on the therapist's and participant's faces to quantify their facial expressions at the moment a picture was captured. Further, application of this machine on time-varying faces (their faces during interviews) also quantifies the dynamics of their facial expressions during interviews. Fig. 5 C shows examples of therapist's faces in 20 seconds (200 frames). The model

348 estimated the probability of happy and scared expressions during the 200 frames (every
349 frame involves one face). Fig. 5 D-1 and D-2 shows the therapist's probability of happy
350 and scared expressions during the 200 frames, respectively. In the same way,
351 participants' facial expressions were estimated: Fig.5 D-1 and D-2 shows a participant's
352 probability of happy and scared expressions, respectively. The therapist's and the
353 participant's quantified facial expressions were used to estimate the synchrony of facial
354 expressions. Before we estimated synchrony, we calculated the average of the facial
355 expressions during the interview.

356 $$\bar{e} = \frac{1}{N}\sum_{n \in N} e[n]$$

357 N is the total number of pictures during a session (9100). e[n] indicates the probability
358 of a specific facial expression (such as a happy expression) at time n.

359 **Quantification of complementary, symmetrical, and absolute synchrony for facial**
360 **expressions**

361 Formulas of cross-correlation coefficients for facial expressions were mainly the same
362 as formulas for facial movements, although the formulas for facial expressions changed
363 from $m_{par}[n]$, $m_{th}[n]$, $\overline{m_{par}}$, and $\overline{m_{th}}$ to $e_{par}[n]$, $e_{th}[n]$, $\overline{e_{par}}$, and $\overline{e_{th}}$, respectively.

364 $$\varphi_{par,th}[j] = \{e_{par}[n - \min(j,0)] - \overline{e_{par}}\}\{e_{th}[n + \max(j,0)] - \overline{e_{th}}\}$$

365 $$self_{par}[j] = \sum_{n=1}^{M-|j|} \{e_{par}[n - \min(j,0)] - \overline{e_{par}}\}^2$$

$$self_{th}[j] = \sum_{n=1}^{M-|j|} \{e_{th}[n + max(j,0)] - \overline{e_{th}}\}^2$$

$e_{par}[n]$ and $e_{th}[n]$ represent the participant's and therapist's facial movement at time *n*. $\overline{e_{par}}$ and $\overline{e_{th}}$ are the averages of the facial movements.

Quantification of pseudo synchrony for both facial movements and expressions

The 7150 seven-second portions (70 faces in each portion) of participants' faces were randomly paired with the 7150 seven-second portions of the therapist's faces. Among them, 125 pairs were in the same session; these pairs were excluded. The other 7025 pairs never occurred in an actual interview; they were regarded as pseudo pairs. We calculated the synchrony of pseudo pairs as pseudo synchrony of facial movements. The pseudo pairs were also used to calculate pseudo synchrony of facial expressions.

Analysis

To test hypothesis 0, we used t-test and Cohen's d. Pearson's correlation was also used to test hypothesis 1, 2, 3A, and 3B. Hierarchical regression analysis was also used to test hypothesis 4. For the purpose of exploratory analysis, we did not adjust *p* values in our analysis.

Ethical considerations

Our study was approved by an ethics committee of a national university in Japan. Furthermore, all procedures were conducted in accordance with guidelines for studies involving human participants, the ethical standards of the institutional research committee, and the revised 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Results

Comparison of genuine synchrony and pseudo synchrony (Hypothesis 0)

We compared symmetrical, complementary, and absolute synchrony of facial movements between real (genuine) and random (pseudo) pairs. Synchronies of facial movements for the genuine pair were mostly lower than for the pseudo pair (Table 1). Compared to complementary synchronies (4/10), symmetrical and absolute synchronies showed high rates of significant differences (9/10, 8/10, respectively). These findings indicate that symmetrical and absolute synchronies were more robust for facial movements than the complementary synchronies.

Similarly, we compared symmetrical, complementary, and absolute synchrony of facial expressions between real (genuine) and random (pseudo) pairs. The synchrony of facial expressions for the genuine pair was also mostly lower than for the pseudo pair (Table 2). Except for the complementary synchrony of disgust, the other synchronies show that the synchrony of facial expressions for the genuine pair was significantly lower than for the pseudo pair. These findings indicate that the synchrony of facial expressions was robust regardless of the direction of synchrony.

Relevance between facial expressions and movements (Hypothesis 2)

Before we check correlations between facial movements and expressions, we compared these movements and expressions between the participants and their therapist. Tables 3 and 4 show the average of the participants' and the therapist's facial movements. The therapist showed significantly higher facial movements than the participants in all facial areas, including the jaw (*paired t* = -15.080, $p < .001$), right eyebrow (*paired t* = -9.119, $p < .001$), left eyebrow (*paired t* = -8.578, $p < .001$), nasal cavity (*paired t* = -23.715, $p < .001$), ridge of nose (*paired t* = -22.981, $p < .001$), right eye (*paired t* = -13.042, $p < .001$), left eye (*paired t* = -18.668, $p < .001$), outer lip (*paired t* = -20.210, $p < .001$), inner lip (*paired t* = -18.489, $p < .001$), and face (*paired t* = -18.417, $p < .001$). These findings indicated that the therapist's face moved more frequently and widely than the participants' during the interviews.

Similarly, we compared the facial expressions of the participants and the therapist (Tables 3 and 4). Participants showed stronger disgust (*paired t* = 5.104, $p < .001$), happy (*paired t* = 4.188, $p < .001$), surprise (*paired t* = 4.657, $p < .001$), and neutral expressions (*paired t* = 7.590, $p < .001$) than their therapist. On the other hand, the therapist showed stronger angry (*paired t* = -7.607, $p < .001$), scared (*paired t* = -7.427, $p < .001$), and sad expressions (*paired t* = -14.479, $p < .001$) than his participants. These findings indicated that distributions of facial expressions are different between participants and their therapist.

Table 3 shows correlations between participants' facial expressions and their facial movements. Their angry expressions were positively correlated with their jaw, right eyebrow, left eyebrow, nasal cavity, ridge of nose, right eye, left eye, and total face movements (Table 3). Furthermore, their sad expressions were positively correlated with their jaw, left eyebrow, nasal cavity, ridge of nose, right eye, left eye, outer lips, inner lips, and total face movements (Table 3). Moreover, their neutral facial expressions were negatively correlated with all of their facial movements (Table 3). These findings indicate that participants' facial movements were related to their negative emotional expressions.

Table 4 shows correlations between the therapist's facial expressions and his facial movements. In contrast to the participants' findings, the therapist's scared expressions were negatively correlated with his jaw, left eyebrow, right eye, left eye, and face movements. Furthermore, the therapist's happy expressions were positively correlated with his nasal cavity, ridge of nose, outer lips, and inner lips movements. These findings indicated that the therapist's facial movements were related to their increased positive emotions and decreased negative emotions.

Relevance between Therapeutic Alliance and NVS of Facial Movements (Hypothesis 1 and 3A)

Fig. 4A shows examples of symmetrical synchrony of left eye movements during a structured psychotherapeutic interview for the high therapeutic alliance and low therapeutic alliance scorers. The strong red area indicates strong symmetrical synchronies. The examples imply that the high therapeutic alliance scorer's symmetrical synchronies were weaker than those of the low therapeutic alliance scorer. Fig. 4B shows examples of complementary synchrony of left eye movements during an interview. The strong blue area indicates strong complementary synchronies. In contrast to symmetrical synchrony, the examples imply that the high therapeutic alliance scorer's complementary synchronies were stronger than those of the low therapeutic alliance scorer. Table 5 also confirmed this tendency. The symmetrical synchronies of facial movements, including eye and mouth movements, were negatively correlated with therapeutic alliance, whereas the complementary synchronies of a facial movement, including left eyebrow movements, were positively correlated with therapeutic alliance, although several correlations did not reach significant levels. These findings indicated that the symmetrical synchrony of facial movements was negatively correlated with therapeutic alliance. Table 6 shows the correlations between therapeutic alliance and absolute synchrony of facial movements. Unlike Table 5, Table 6 did not show any significant relations between therapeutic alliance and absolute synchrony of facial movements.

Relevance between Therapeutic Alliance and NVS of Facial Expressions (Hypothesis 3B)

Table 7 shows the correlations between therapeutic alliance and synchrony of facial expressions. The symmetrical synchronies of facial expressions, including angry, happy, and neutral, were positively correlated with therapeutic alliance. Furthermore, the complementary synchronies of facial expressions, including scared, happy, and sad, were also positively correlated with therapeutic alliance. The correlations between symmetrical synchrony and complementary synchrony were also positive regarding angry, scared, sad, surprise, and neutral expressions (Table 7). These findings indicated that both complementary and symmetrical synchronies of facial expressions were positively correlated with therapeutic alliance.

Prediction of Therapeutic alliance from NVS of Facial Movements and Facial Expressions (Hypothesis 4)

Before we test the hierarchical regression analysis on therapeutic alliance from the synchrony of facial movements and expressions, we indicated the correlations among them (Table 8). Table 8 shows that therapeutic alliance was positively correlated with symmetrical synchrony of scared expressions, complementary synchrony of happy expressions, and complementary synchrony of scared expressions. On the other hand, therapeutic alliance was negatively correlated with the symmetrical synchrony of right eye and left eye movements. Further, symmetrical synchrony of left eye movements was negatively correlated with complementary synchrony of scared expressions, symmetrical synchrony of happy expressions, and symmetrical synchrony of scared expressions. These findings suggested that both symmetrical and complementary synchronies of facial expressions were positively related to therapeutic alliance; however, the symmetrical synchrony of right and left eye movements was negatively related to therapeutic alliance.

Table 9 shows the hierarchical regression analysis on therapeutic alliance from symmetrical and complementary synchronies. Model 1 predicted therapeutic alliance from participants’ age and sex only. Model 2 included both the participants' and the therapist's facial movements and expressions as independent variables. Model 3 included complementary and symmetrical synchronies of happy and scared emotions as independent variables. Model 3 also included complementary and symmetrical synchronies of right and left eye movements as independent variables. Model 2 indicated that participants’ happy expressions during the interviews predicted a positive therapeutic alliance, whereas the therapist’s scared expression during the interviews predicted a negative therapeutic alliance. Further, model 3 also indicated that inclusion of complementary and symmetrical synchronies increased the contribution rate significantly (Table 9). Further, symmetrical synchrony of left eye movements predicted a negative therapeutic alliance; however, complementary synchrony of left eye movements predicted a positive therapeutic alliance. Table 10 used absolute synchronies of facial expressions and movements, and predicted therapeutic alliance similar to Table 9. Unlike Table 9, model 3 did not increase the contribution rate.

Discussion

The current study used video imaging methods and quantified facial movements and facial expressions for every 100 milliseconds. Our machine-based method measured facial movements and expressions precisely within a short time and without a human rater's bias (Bernieri et al., 1994), similar to previous studies (Arriaga et al., 2017; Levi & Hassner, 2015; Matsugu et al., 2003; Ramseyer & Tschacher, 2011; Schmidt et al., 2012). Our extension of participants into the Asian population is also important for generalizing the findings of NVS (Bernieri, 1988; Condon & Ogston, 1966; Gatewood & Rosenwein, 1981; Lakin & Chartrand, 2003), similar to a previous study (Kimura & Daibo, 2006). Our findings can summarize the genuine synchrony, speaker role, symmetry/complementary synchrony, and the meaning of NVS with regards to facial parts.

Lower Scores of Synchrony for Genuine Pairs than for Pseudo Pairs (Hypothesis 0)

Our study confirmed that the synchrony of facial movements for the genuine pair was significantly different from the synchrony of the pseudo pair. Yet, our study found that the synchrony of facial movements was lower for genuine pairs than for pseudo pairs, although previous studies of body movements supported that the synchrony of movements was higher for genuine pairs than for the pseudo pairs (Kupper et al., 2015; Lavelle et al., 2013; Paulick et al., 2018; Tschacher & Pfammatter, 2016). The inconsistency of the findings between current and previous studies comes from the differences of active frames between these movements. The body movements were mostly inactive for most frames (a frame is 100 milliseconds) and became rapidly active for specific frames (Tschacher et al., 2014). The random pairs of body movements missed these specific active frames, so the synchrony of pseudo pairs was lowered. On the other hand, facial movements were mostly active during most frames; these frames were regarded as active frames (Fig.1 D, Table 3, and Table 4). Consequently, the random pairs of facial movements did not miss the active frames. Furthermore, the pseudo pairs involved so many individuals that individual differences of pseudo pairs could increase the deviation from the average, which directly increases the size of synchrony among the pseudo pairs. As a result, the synchrony of pseudo pairs in facial movements could be increased. The same discussion can be applicable in electromyography-based emotion encoding (Riehle et al., 2017) and machine-based emotion encoding. The former’s active frames were rare because of a high threshold of activation (Riehle & Lincoln, 2018), whereas the latter’s active frames were frequent because it had no threshold of activation.

Speaker role moderates the relevance between facial movements and facial expressions (Hypothesis 2)

Our study also confirmed the links between eye movements and negative emotions among participants. Like previous studies (Baron-Cohen et al., 2001; D’Mello et al., 2007; Lee et al., 2014), participants’ eye movements were linked with angry and sad expressions. Diagnostic interviews by a clinical psychologist are considered to be stressful for the participants. Hence, it is natural that their facial movements were linked with these negative facial expressions. On the other hand, our study did not confirm the links of eye movements with regards to the clinical psychologist. Actually, his eye movements were negatively linked with his scared expression (Table 4). Further, his outer and inner lip movements were positively linked with his happy expression, which did not appear in these participants (Table 3, 4). The inconsistency of facial expressions between the participants and therapist might come from role differences. During the diagnostic interview, the psychologist has to build therapeutic alliance with his participants, so he intentionally interacts with the participants (Elvins & Green, 2008; Martin et al., 2000). Actually, the volume of his facial movement was higher than the volume of the facial movement by the participants (Table 3, 4). Further, his eye movements were also more rapid than the participants' eye movements (Fig1.D). These data indicated that a diagnostic interview motivated him to build a therapeutic alliance; consequently, his movements might be linked with prosocial emotional expressions rather than negative emotional expressions. Still, our therapist's data was only from a male therapist so these findings might be originated from a peculiarity of him. Hence, generalization of current relevance between therapist's facial movements and facial expressions (Table 4) needs caution.

Complementary and Symmetrical Synchronies of Facial Movements and Facial Expressions (Hypothesis 1, 3A, 3B)

Unlike NVS of many movements (Bernieri, 1988; McFarland, 2001; Miles et al., 2011;

Repp & Su, 2013; Semin & Cacioppo, 2008; Vacharkulksemsuk & Fredrickson, 2012; Vicaria & Dickens, 2016; Won et al., 2014), we did not find any link between absolute synchrony of facial movements and therapeutic alliance (Table 6). Detailed analysis also found that complementary synchrony of facial movements was positively linked with therapeutic alliance, whereas symmetrical synchrony was negatively linked with therapeutic alliance (Table 5). These findings indicated that absolute synchrony of facial movements cancelled the positive effects of complementary synchrony and the negative effects of symmetrical synchrony on therapeutic alliance, so that no significant link was found between the absolute synchrony of facial movements and therapeutic alliance. Still, it is unclear why symmetrical and complementary synchrony of facial expressions indicated correlations with therapeutic alliance in the same direction (Table 7), while the synchrony of facial movements did not (Table 5).

This inconsistency can be explained by the stability of facial expressions and volatility of facial movements. For encoding of facial expressions, emotion-relevant facial movements were selected and emotion-irrelevant facial movements were discarded. Meanwhile, for encoding of facial movements, all facial movements were encoded. This indicates that all one’s facial movements affected all the other’s facial movements; that is, NVS of facial movements is volatile. The volatility of NVS of facial movements might require a sensitive index, such as complementary and symmetrical synchronies, to capture these NVSs. In contrast, one’s emotional-irrelevant facial movements did not affect the other's facial expressions; that is, NVS of facial expressions is stable regarding emotional-irrelevant facial movements. The stability of the NVS of facial expressions might require total volume, such as the absolute values of synchronies, to capture these NVSs. Hence, absolute values of synchronies fit well with the NVS of facial expressions, but not with the NVS of facial movements (Table 8). Although complementary and symmetrical synchronies might be necessary for assessing the NVS of facial movements, they could also be useful for assessing the NVS of body movements. If complementary and symmetrical communication synchronies exist in NVS of body movements, symmetrical synchronies might be prevalent in competitive settings (Lozza et al., 2018; Tschacher et al., 2014), whereas complementary synchronies might be prevalent in collaborative settings (Bernieri, 1988; Ramseyer & Tschacher, 2011; Shockley et al., 2003). Further, reanalysis of head movements from the perspective of symmetrical and complementary synchronies is also interesting (Ramseyer & Tschacher, 2014). Testing these hypotheses is important to clarify the direction of synchrony associated with NVS.

Meanings of NVS with regards to Facial Movements and Expressions (Hypothesis 4)

Complementary and symmetrical synchronies of scared expressions were positively linked with therapeutic alliance. Furthermore, symmetrical synchrony of happy expressions was positively linked with therapeutic alliance, same as symmetrical synchrony of scared expressions. Absolute synchronies of happy and scared expressions were also positively correlated with therapeutic alliance. These findings indicated that the total synchrony of facial expressions is linked with therapeutic alliance, regardless of synchrony directions (symmetrical or complementary) and emotional values (positive or negative emotions). The synchrony of facial expressions might be regarded as an emotional interaction between participants and the therapist, which positively affect therapeutic alliance (Elvins & Green, 2008; Martin et al., 2000). Many studies have found that one's mimicking of another's facial expressions affect one's emotional experience and the collaborative relationship between them (Chartrand & Bargh, 1999; Chartrand & Lakin, 2013; Shockley et al., 2003). Symmetrical synchrony of facial expressions during an interview can be regarded as mimicry of facial expressions between the participants and the therapist within a 2 second delay, similar to previous studies (Riehle et al., 2017; Riehle & Lincoln, 2018). Our study measured the synchrony at 100 milliseconds; consequently, most synchronies could be regarded as at unconscious level (Lakin & Chartrand, 2003). Complementary synchrony of facial expressions was positively related to symmetrical synchrony of facial expressions (Table 7); consequently, the complementary synchrony of facial expressions could be regarded as a by-product of mimicry of facial expressions.

Contrary to NVS of facial expressions, symmetrical synchrony of left eye movements was negatively correlated with therapeutic alliance. Hierarchical regression models also confirmed that symmetrical synchrony of left eye movements predicted a negative therapeutic alliance. Further, symmetrical synchrony of left eye movements was negatively related to complementary synchrony of scared expressions, symmetrical synchrony of happy expressions, and symmetrical synchrony of scared expressions. When we regard the synchrony of facial expressions as an emotional interaction between the participants and the therapist (Chartrand & Bargh, 1999; Chartrand & Lakin, 2013; Shockley et al., 2003), symmetrical synchrony of left eye movements can be regarded as a blocker of emotional interaction between them. Our model also found that the complementary synchrony of left eye movements positively predicted therapeutic alliance. These findings indicate that complementary synchrony of left eye movements could be smooth emotional turn taking, whereas the symmetrical synchrony of left eye movements was conflict of emotional turn taking. NVS of left eye movements can be an index of emotional turn taking at a micro visual level. Interestingly, symmetrical synchrony of inner and outer lips was also negatively correlated with therapeutic alliance. The symmetrical synchrony of mouth movements might imply an error of turn taking and an increased number of cross-talk. These findings also indicated that symmetrical synchrony of eye and mouth movements might be a blocker index of emotional turn taking. The current findings extended the index of emotional turn taking from the prosody level (Acosta & Ward, 2011) to the micro visual level. Still, coefficients of therapist's left eye movement were deviant from those in his other movements and participants' movements (Table 3 and 4), the current findings might be originated from a peculiarity of the interviewer. Hence, generalization of synchrony of left eye movements during therapy (Table 8, 9 and 10) needs caution.

Limitations

Despite these positive findings and implications, our study had four limitations. First, our therapist was unaware of the current hypothesis because he had another hypothesis during the experiment (Yokotani et al., 2018); however, he was not naive to the current research question because he was a main analyzer and main writer of our paper. Hence, the therapist might have been biased as an experimenter, even though the control of eye movements every 100 milliseconds during the interview might have been impossible. Second, encoding of facial expressions was still under development. Especially, differentiation between negative emotions was still difficult for machines because several areas, such as a frown, were quite similar to angry and disgust expressions (Arriaga et al., 2017). Further, machine learning from a Western face database might not fit well with an emotion recognition of Asian faces (Carrier et al., 2013). Addition of Asian faces to the database is required for further study. Third, our setting had only one male therapist with glasses; thus, we could not clarify the gender effect, especially among female participant-female therapist pairs. Gender differences might affect NVS of facial movements (Stratou, Hoegen, Lucas, & Gratch, 2017). The gender effects need to be controlled. Further, our emotion recognition model frequently confused the therapist's dark glass frames with his frowning (Arriaga et al., 2017), so the model wrongly believes that he is frowning and mistakenly overestimate the probability of his angry expression; the effects of glasses also need to be controlled. Therefore, future studies should include female therapists and therapists without glasses. Fourth, we did not include verbal data; therefore, we cannot adjust the verbal effect, such as cross-talk, on symmetrical synchrony of facial movements and therapeutic alliance. Addition of verbal data analysis could purify the nonverbal effects of synchrony regarding facial movements and expressions on therapeutic alliance.

Conclusion

Our study analyzed NVS of both facial expressions and facial movements using video imaging techniques (Bradski & Kaehler, 2000; King, 2009; Yokotani et al., 2018), standardized face (Langlois & Roggman, 1990), and normalized cross-correlations (Yoo & Han, 2009). We established two points. First, NVS of facial expressions during the interviews indicated an emotional interaction between the participants and the therapist. Taking into account that a frame is 100 milliseconds, the emotional interaction can be at an unconscious level. Hence, NVS of facial expressions can be regarded as an index of emotional interaction at an unconscious level (Lakin & Chartrand, 2003). Second, symmetrical synchrony of left eye movements predicted a negative therapeutic alliance. Further, the symmetrical synchrony of left eye movements was also negatively related to the synchrony of facial expressions. These findings indicated that the symmetrical synchrony of left eye movements can be a blocker of emotional interaction. In other words, symmetrical synchrony of left eye movements might be a negative predictor of therapeutic alliance, similar to previous studies (de la Peña, Friedlander, Escudero, & Heatherington, 2012; Escudero et al., 1997; Heatherington & Friedlander, 1990; Watzlawick et al., 2011), although the synchrony of most parts was a positive predictor of therapeutic alliance (Paladino et al., 2010; Repp & Su, 2013; Semin & Cacioppo, 2008; Vicaria & Dickens, 2016). These findings need to be replicated in a future study with a new dataset.

The video imaging technique that we used (Ramseyer & Tschacher, 2011; Yokotani et al., 2018) could reduce the cost and time for evaluation of NVS and provide detailed analysis of NVS (Bernieri, 1988; Condon & Ogston, 1966; Gatewood & Rosenwein, 1981; Lakin & Chartrand, 2003). Addition of facial movements and expression to the NVS studies could extend previous findings of NVS of body/head movements (Kupper et al., 2015; Paulick et al., 2017, 2018; Ramseyer & Tschacher, 2014) to NVS of facial movements (Hughes & Aung, 2018; Künecke, Wilhelm, & Sommer, 2017; Riehle et al., 2017) and contribute to the understanding of nonverbal behavior in dyadic relationships (Schmidt et al., 2012; Won et al., 2014).

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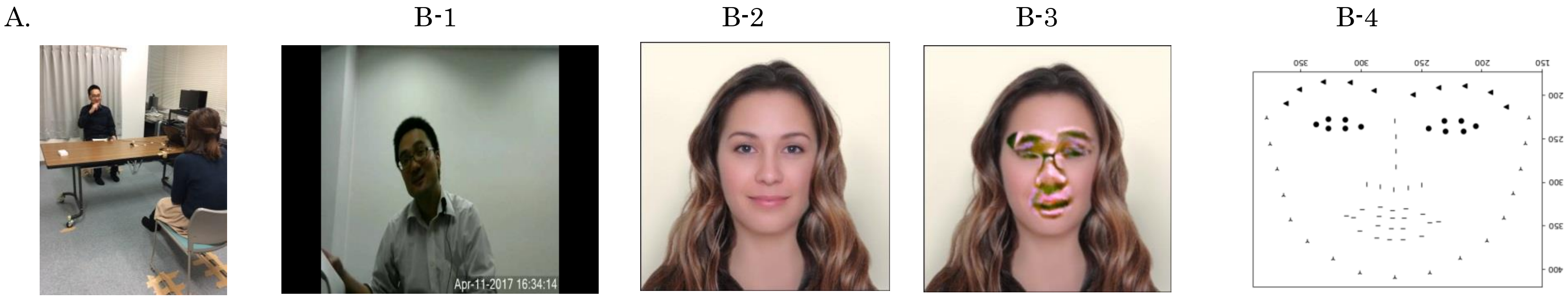
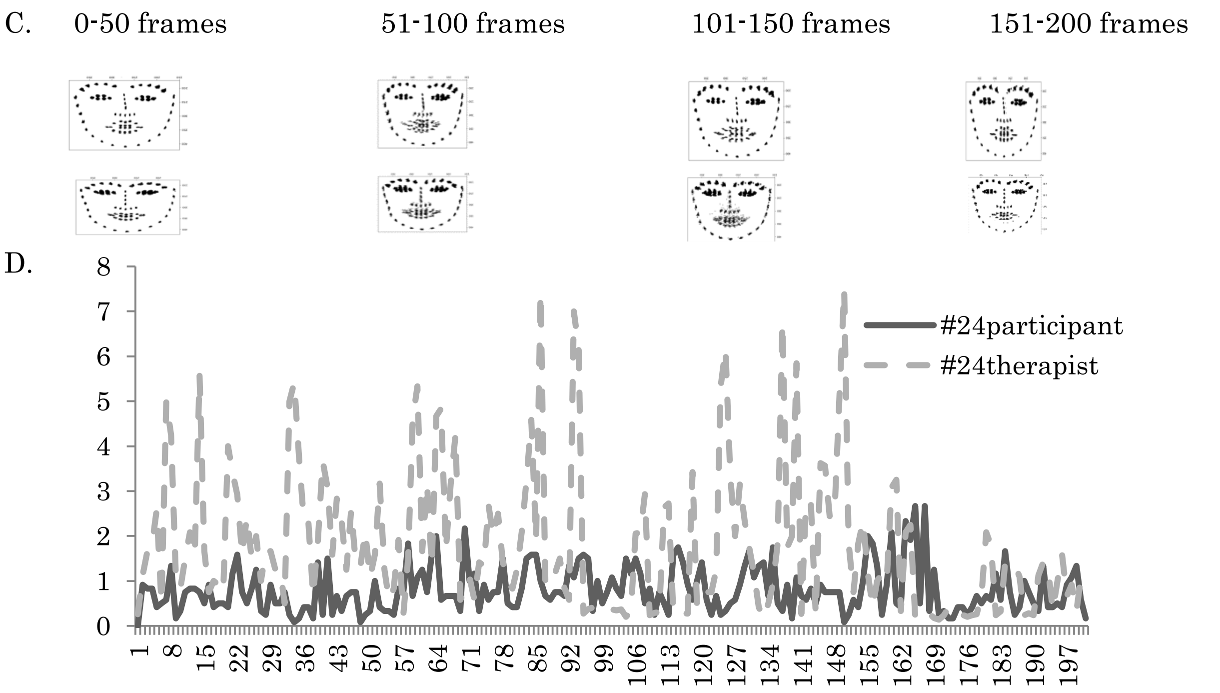
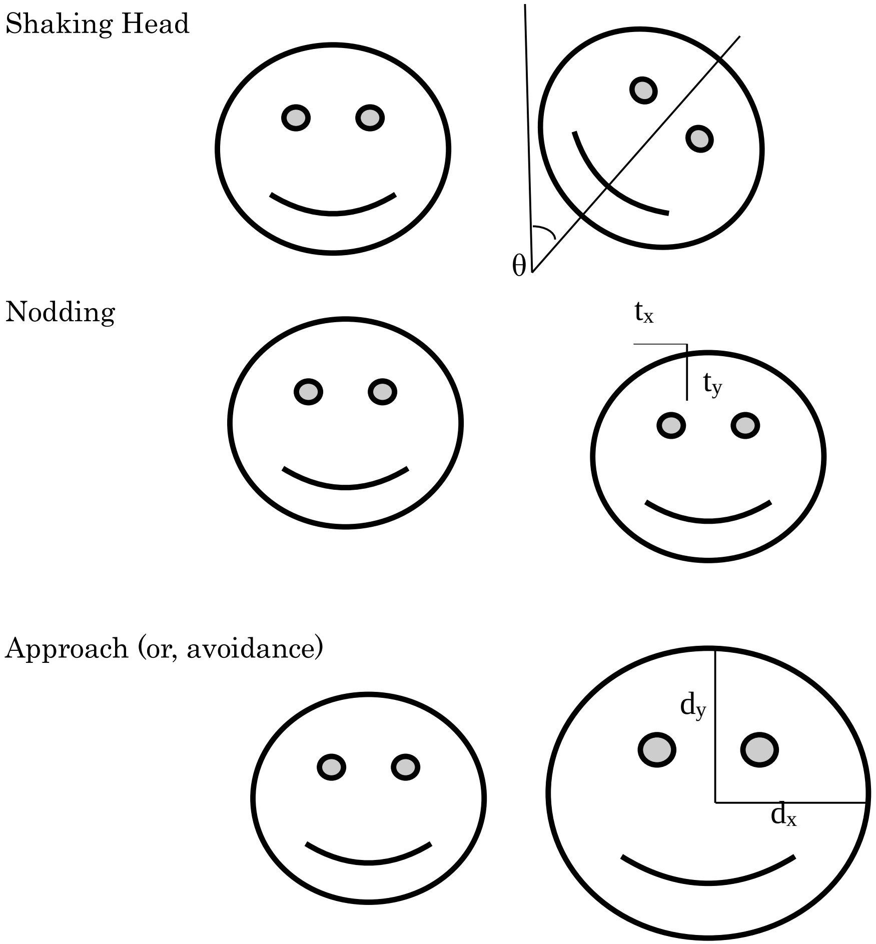




A shows the interview setting. B shows the transformation of a therapist's face in a picture into the standardized face with landmarks: Raw picture (B-1) was transformed with reference to an average female face (B-2). The standardized face (B-3) had 68 standardized points (B-4). C shows facial movements during 200 frames (20 seconds). The upper and lower faces in C represent a participant's and a therapist's facial movements, respectively. Corresponding to C, D shows the participant's and therapist's left eye movements.

Fig. 1. Experimental setting and an example analysis of facial movements



When a participant shakes his or her head, the head will be rotated (θ). When the participant nods, the head will be moved (t_x, t_y). Further, when the participant approaches the camera, his or her facial size will be expanded (d_x, d_y). These head movements change the positions of facial landmarks, regardless of actual facial movements. To minimize the effects of these head movements on facial movements, we performed a coordinate transformation from captured positions of facial landmarks (x, y) to the transferred facial landmarks (x', y') through an affine formula:

$$[x', y', 1] = [x \;\; , y \;\; , 1]\begin{bmatrix} dx\cos\theta & \sin\theta & 0 \\ -\sin\theta & dy\cos\theta & 0 \\ tx & ty & 1 \end{bmatrix}$$

Note: The θ, d_x, d_y, t_x, and t_y were estimated through averaged female face and ordinary procrustes analysis.

Fig. 2. Affine formula was used to prevent the effects of head movements on facial movements

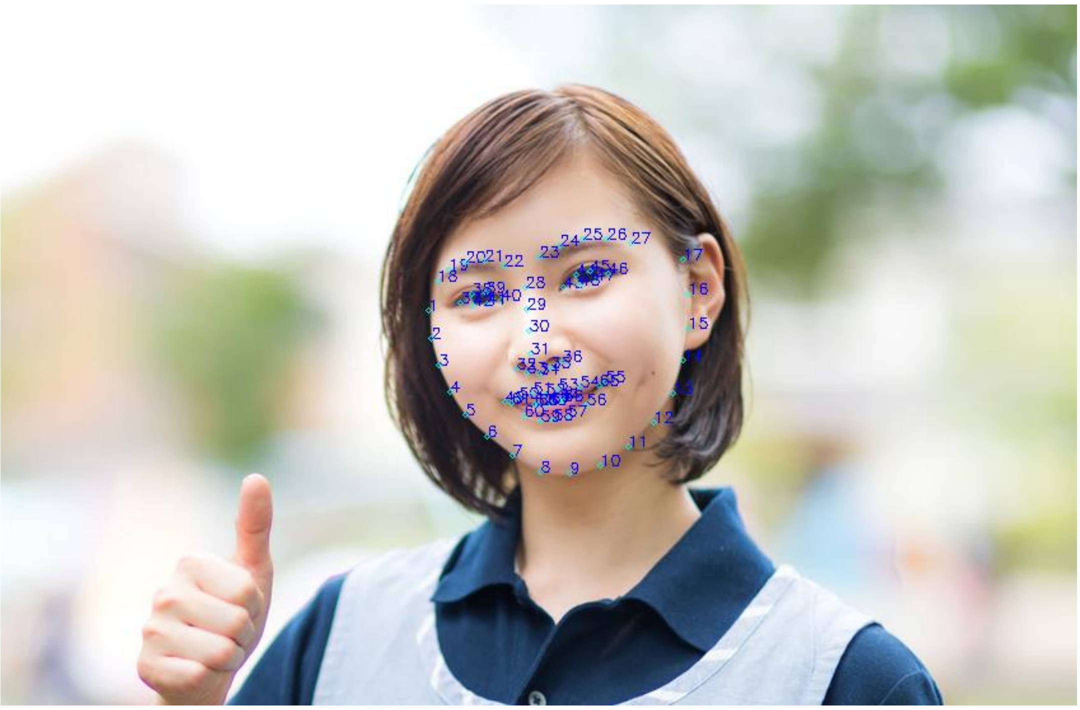
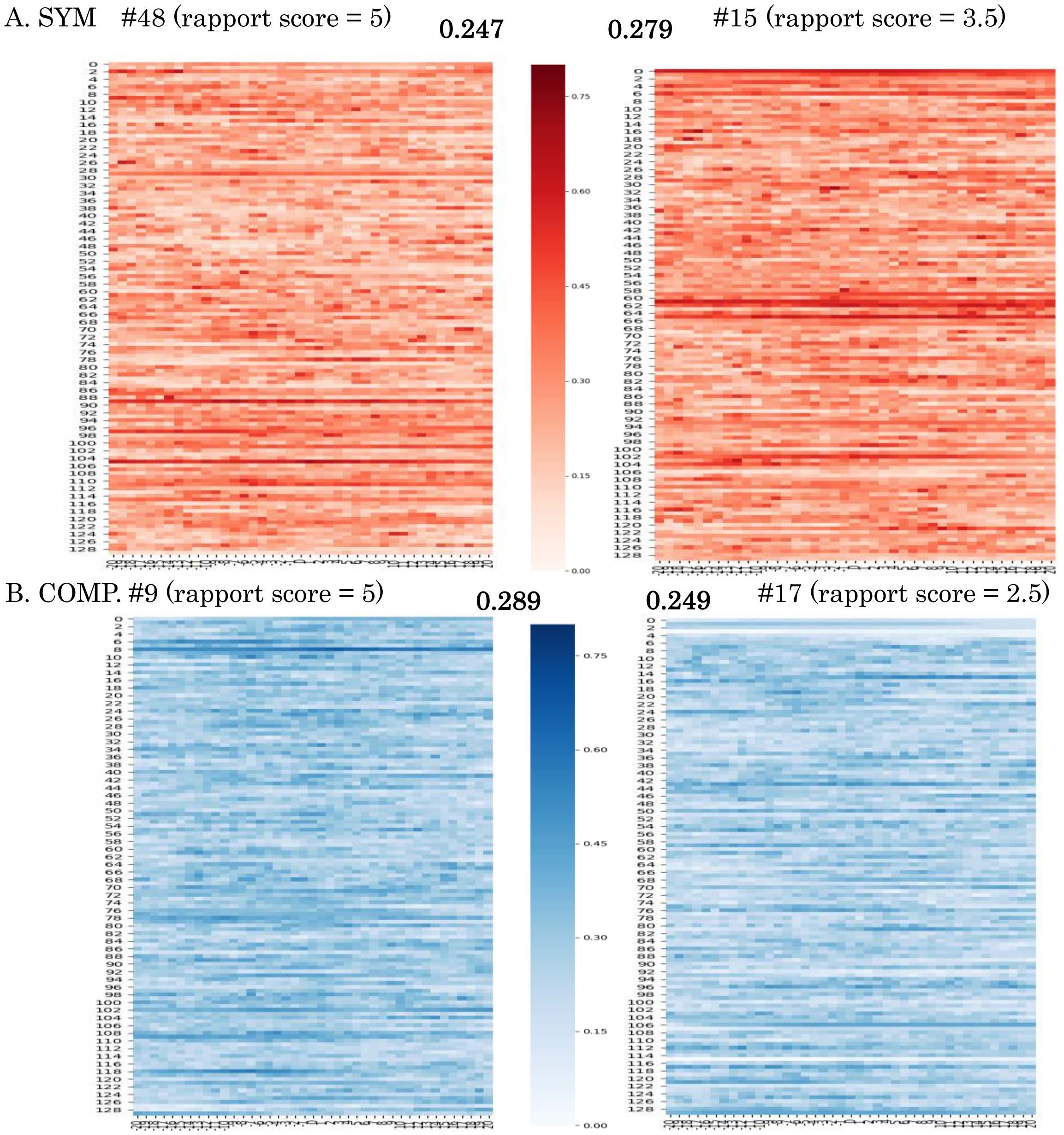


Fig.3. Sixty eight landmarks on a face

Notes: These landmarks indicate the jaw (marks 1–17), eyebrows (right eyebrow: marks 18–22; left eyebrow: marks 23–27), nose (nasal cavity: marks 28–31; ridge of nose: marks 32–36), eyes (right eye: marks 37-42; left eye: marks 43-48), mouth (outer lip: marks 49–60; inner lip: marks 61–68), and face (marks:1-68).



A shows symmetrical synchrony of left eye movements between clients (#48 with a high rapport score, #15 with a low rapport score) and a therapist. The strong red color indicates strong symmetrical synchrony. The y-axis indicates the duration of each session (1 unit includes 70 frames [7 seconds]). The x-axis indicates the synchrony time lag between the therapist and client: -20 indicates that the therapist's movement was delayed for 20 frames (2 seconds) compared to the client's movement, whereas 20 indicates therapist's movement was ahead by 20 frames. The bold scores indicate the total average of symmetrical synchrony during the session. Similarly, B shows complementary synchrony of left eye movements between clients and a therapist. The strong blue color indicates strong complementary synchrony. SYM: Symmetrical synchrony, COMP: Complementary Synchrony

Fig. 4. Synchrony of left eye movements during an interview

A-1

A-2

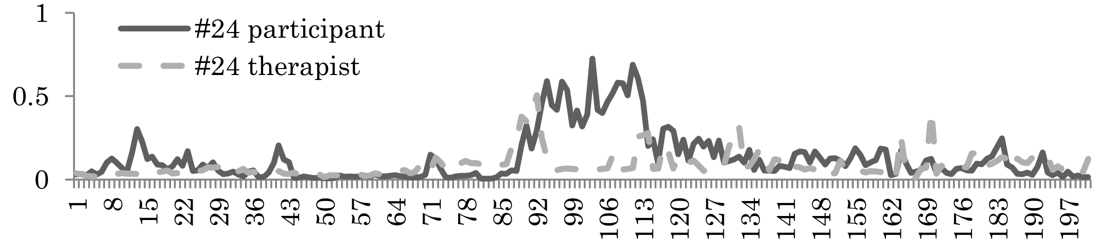
A-3

B

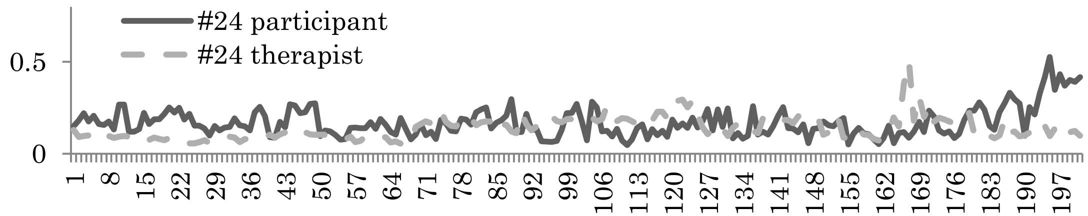
	A-1(Smile)	A-2(Scream)	A-3(Blame)
Happy	0.97034	0.0943688	0.00164537
Scared	0.00041955	0.40032	0.176243
Angry	0.00026209	0.290947	0.497819
Disgust	1.2564E-05	0.171526	0.217929
Sad	0.00041328	0.0179842	0.025653
Surprised	0.00013299	0.00776567	0.0596317
Neutral	0.0284191	0.0170886	0.0210791

C.

D-1. Happy



D-2. Scared



A-1, A-2, and A-3 show typical happy, scared, and angry faces. B shows the machine-estimated probabilities of each emotion based on these faces. C shows the therapist's facial expressions during 200 frames (20 seconds). The machine estimated probabilities of emotion during C. D-1 shows the participant's and therapist's probabilities of happy emotion. Similarly, D-2 shows their probabilities of scared emotion.

Fig. 5. Encoding of facial expression and an example analysis of facial expressions

Table 1. Comparison of Synchrony of Facial Movements between Genuine and Pseudo Pairs

		Genuine		Pseud					
		M	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
Jaw	SYM.	0.284	0.010	0.286	0.005	-1.35	82.40	*n.s.*	-0.26
	COMP.	0.281	0.009	0.283	0.006	-1.60	91.88	*n.s.*	-0.30
	ABS.	0.565	0.016	0.569	0.006	-1.93	68.05	+	-0.37
Right Eyebrow	SYM.	0.282	0.009	0.289	0.006	-4.30	93.93	***	-0.82
	COMP.	0.279	0.008	0.285	0.007	-4.38	103.05	***	-0.84
	ABS.	0.561	0.013	0.573	0.006	-6.79	75.90	***	-1.30
Left Eyebrow	SYM.	0.280	0.010	0.289	0.007	-6.02	101.85	***	-1.15
	COMP.	0.281	0.009	0.283	0.007	-1.75	104.03	+	-0.33
	ABS.	0.560	0.013	0.573	0.006	-6.35	74.32	***	-1.21
Nasal Cavity	SYM.	0.273	0.009	0.280	0.006	-4.51	91.28	***	-0.86
	COMP.	0.271	0.010	0.272	0.006	-0.54	88.66	*n.s.*	-0.10
	ABS.	0.544	0.013	0.552	0.006	-3.88	75.27	***	-0.74
Ridge of Nose	SYM.	0.271	0.009	0.276	0.005	-3.66	87.21	***	-0.70
	COMP.	0.265	0.010	0.266	0.006	-0.50	85.27	*n.s.*	-0.10
	ABS.	0.537	0.012	0.543	0.005	-3.28	70.99	**	-0.63
Right Eye	SYM.	0.273	0.011	0.280	0.006	-4.38	85.62	***	-0.83
	COMP.	0.269	0.008	0.274	0.007	-3.39	105.03	**	-0.65
	ABS.	0.541	0.015	0.554	0.006	-5.64	70.18	***	-1.08
Left Eye	SYM.	0.267	0.010	0.274	0.006	-4.17	84.91	***	-0.80
	COMP.	0.264	0.009	0.267	0.006	-2.23	98.23	*	-0.43
	ABS.	0.532	0.015	0.541	0.007	-4.43	76.46	***	-0.84
Outer Lip	SYM.	0.268	0.011	0.275	0.008	-4.01	95.89	***	-0.76
	COMP.	0.266	0.012	0.265	0.006	0.99	83.32	*n.s.*	0.19
	ABS.	0.534	0.014	0.540	0.006	-2.71	75.15	**	-0.52
Inner Lip	SYM.	0.268	0.012	0.275	0.007	-3.86	90.77	***	-0.74
	COMP.	0.267	0.011	0.264	0.006	1.48	83.84	*n.s.*	0.28
	ABS.	0.535	0.014	0.540	0.006	-2.25	72.49	*	-0.43
Face	SYM.	0.282	0.013	0.290	0.007	-4.03	86.34	***	-0.77
	COMP.	0.284	0.011	0.286	0.007	-1.18	93.91	*n.s.*	-0.23
	ABS.	0.566	0.017	0.576	0.006	-4.25	70.13	***	-0.81

Note: SYM.: Symmetrical synchrony, COMP.: Complementary synchrony, ABS.: Absolute synchrony, ***: $p < .001$, **: $p < .01$, *: $p < .05$, +: $p < .010$, n.s.: no significance

Table 2. Comparison of Synchrony of Facial Emotions between Genuine and Pseudo Pairs

		Genuine		Pseud					
		M	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
Angry	SYM.	0.257	0.031	0.323	0.018	-13.5	86.8	***	-2.6
	COMP.	0.253	0.027	0.306	0.018	-11.7	94.6	***	-2.2
	ABS.	0.510	0.051	0.628	0.011	-16.9	58.9	***	-3.2
Disgust	SYM.	0.297	0.029	0.410	0.027	-21.2	107.5	***	-4.0
	COMP.	0.234	0.025	0.236	0.015	-0.4	88.3	*n.s.*	-0.1
	ABS.	0.531	0.037	0.646	0.019	-20.4	79.8	***	-3.9
Scared	SYM.	0.262	0.028	0.308	0.014	-10.8	79.2	***	-2.1
	COMP.	0.252	0.026	0.290	0.014	-9.5	83.9	***	-1.8
	ABS.	0.514	0.050	0.598	0.010	-12.3	58.6	***	-2.4
Happy	SYM.	0.295	0.048	0.326	0.020	-4.5	72.9	***	-0.9
	COMP.	0.242	0.027	0.295	0.020	-11.7	98.8	***	-2.2
	ABS.	0.538	0.057	0.621	0.012	-10.7	59.2	***	-2.0
Sad	SYM.	0.253	0.028	0.278	0.014	-5.9	81.0	***	-1.1
	COMP.	0.247	0.025	0.278	0.013	-8.2	82.3	***	-1.6
	ABS.	0.501	0.048	0.557	0.009	-8.5	58.2	***	-1.6
Surprise	SYM.	0.258	0.033	0.325	0.024	-12.2	99.0	***	-2.3
	COMP.	0.222	0.030	0.240	0.017	-3.9	84.9	***	-0.7
	ABS.	0.481	0.051	0.566	0.017	-11.6	66.2	***	-2.2
Neutral	SYM.	0.271	0.033	0.309	0.016	-7.7	76.7	***	-1.5
	COMP.	0.260	0.029	0.309	0.016	-10.9	85.9	***	-2.1
	ABS.	0.531	0.054	0.618	0.012	-11.6	59.3	***	-2.2

Note: SYM.: Symmetrical synchrony, ABS.: Absolute synchrony, COMP.: Complementary synchrony, ***: $p < .001$, *n.s.*: no significance

Table 3. Correlations between Participants' Facial Movements and Expressions

	M	S.D.	V. Angry (Par.)	V. Disgust (Par.)	V. Scared (Par.)	V. Happy (Par.)	V. Sad (Par.)	V. Surprised (Par.)	V. Neutral (Par.)
M			.160	.028	.115	.149	.091	.022	.432
S.D.			.107	.028	.075	.113	.035	.022	.170
V. Jaw(Par.)	.918	.151	.408**	.256	.280*	-.164	.340*	-.115	-.371**
V. Right Eyebrow(Par.)	1.163	.320	.475**	.17	.175	-.008	.26	.007	-.455**
V. Left Eyebrow (Par.)	1.111	.319	.505**	.19	.118	-.092	.276*	-.057	-.391**
V. Nasal Cavity (Par.)	.709	.187	.488**	.277*	.261	-.12	.366**	.049	-.472**
V. Ridge of Nose(Par.)	.658	.138	.302*	.289*	.254	-.098	.358**	.007	-.362**
V. Right Eye(Par.)	.875	.224	.434**	.17	.198	-.024	.276*	-.055	-.424**
V. Left eye(Par.)	.793	.188	.431**	.123	.082	.001	.291*	-.081	-.380**
V. Outer lips(Par.)	.836	.150	.159	.207	.279*	.048	.312*	-.03	-.351**
V. Inner lips (Par.)	.835	.154	.13	.237	.288*	.09	.317*	-.005	-.375**
V. Face(Par.)	.880	.167	.414**	.235	.244	-.05	.344*	-.049	-.440**

Note. V.: Volume, Par.: Participant, **: $p < .01$, *: $p < .05$

Table 4. Correlations between Therapists' facial Movements and Expressions

	M	S.D.	V. Angry (Th.)	V. Disgust (Th.)	V. Scared (Th.)	V. Happy (Th.)	V. Sad (Th.)	V. Surprised (Th.)	V. Neutral (Th.)
M			.286	.008	.197	.086	.163	.007	.250
S.D.			.036	.008	.020	.018	.010	.001	.031
V. Jaw(Th.)	1.251	.057	.171	-.213	-.301*	-.066	.103	-.053	.058
V. Right Eyebrow(Th.)	1.579	.114	.164	-.265	-.231	-.059	.149	.124	.006
V. Left Eyebrow (Th.)	1.500	.121	.255	-.26	-.293*	-.063	.066	.156	-.034
V. Nasal Cavity (Th.)	1.364	.104	-.175	-.492**	-.212	.282*	.131	.172	.251
V. Ridge of Nose(Th.)	1.224	.118	-.097	-.307*	-.149	.299*	-.144	.450**	.133
V. Right Eye(Th.)	1.287	.077	.037	-.451**	-.637**	.003	.190	.05	.414**
V. Left eye(Th.)	1.314	.094	.063	-.257	-.440**	-.027	.047	.229	.26
V. Outer lips(Th.)	1.371	.127	-.235	-.451**	-.25	.431**	-.097	.451**	.303*
V. Inner lips (Th.)	1.329	.122	-.249	-.457**	-.23	.456**	-.095	.452**	.293*
V. Face(Th.)	1.337	.085	-.045	-.414**	-.334*	.215	.012	.299*	.227

Note. V.: Volume, Th.: Therapist, **: $p < .01$, *: $p < .05$

Table 5. Correlations among Therapeutic Alliance, Symmetrical Synchrony of Facial Movements, and Complementary Synchrony of Facial Movements

	1	2 (SYM.)	3 (SYM.)	4 (SYM.)	5 (SYM.)	6 (SYM.)	7 (SYM.)	8 (SYM.)	9 (SYM.)	10 (SYM.)	11 (SYM.)	12	13	14
1.Therapeutic Alliance	-	-.132	-.183	-.259	-.200	-.206	-.324*	-.325*	-.322*	-.351**	-.333*	-.173	-.240	-.037
2.Jaw (COMP.)	.149	.378**	.596**	.563**	.696**	.616**	.700**	.596**	.685**	.653**	.844**	.110	.151	-.091
3.Right Eyebrow (COMP.)	.25	.613**	.029	.681**	.642**	.543**	.743**	.611**	.391**	.410**	.678**	.200	-.008	-.090
4.Left Eyebrow (COMP.)	.363**	.435**	.644**	.077	.708**	.473**	.578**	.536**	.279*	.274*	.573**	.153	.045	-.014
5.Nasal Cavity (COMP.)	.092	.601**	.587**	.556**	-.077	.835**	.591**	.613**	.617**	.600**	.798**	.159	-.043	-.068
6.Ridge of Nose (COMP.)	.164	.617**	.481**	.514**	.845**	-.165	.570**	.547**	.702**	.697**	.752**	.124	-.126	-.204
7.Right Eye (COMP.)	.042	.565**	.541**	.355**	.611**	.446**	.226	.784**	.554**	.566**	.816**	.252	.096	-.014
8.Left eye (COMP.)	.222	.414**	.480**	.457**	.571**	.425**	.629**	.239	.618**	.606**	.755**	.265	.022	.114
9.Outer lips (COMP.)	.201	.399**	.332*	.280*	.443**	.690**	.271*	.22	-.240	.981**	.829**	.265	.142	-.126
10.Inner lips (COMP.)	.187	.378**	.299*	.279*	.403**	.660**	.229	.208	.976**	-.238	.821**	.281*	.131	-.14
11.Face (COMP.)	.193	.708**	.598**	.507**	.776**	.816**	.593**	.523**	.756**	.724**	-.055	.326*	.113	-.057
12.Age	-.173	-.22	-.224	-.221	-.300*	-.293*	-.073	-.005	-.146	-.151	-.146	-	-.015	.395**
13.Sex	-.240	.190	-.061	-.021	.209	.178	.164	.051	.056	.036	.200	-.020	-	-.020
14.GAF	-.037	-.178	-.335*	-.127	-.208	-.204	-.162	.022	-.024	-.046	-.119	.395**	-0.015	-

Note: The upper triangle indicates symmetrical synchrony, whereas the lower triangle indicates complementary synchrony. The diagonal indicates the correlations between complementary and symmetrical synchrony. COMP.: Complementary synchrony, SYM.: Symmetrical synchrony, **: $p < .01$, *: $p < .05$, Sex (male = 1, female = 0), GAF: Global Assessment of Functioning

Table 6. Correlations among Therapeutic Alliance and Absolute Synchrony of Facial Movements

	2	3	4	5	6	7	8	9	10	11	12	13	14
1.Therapeutic Alliance	.004	.027	.046	-.072	-.014	-.212	-.096	-.093	-.142	-.127	-.173	-.240	-.037
2.Jaw (ABS.)		.614**	.480**	.655**	.664**	.612**	.405**	.629**	.575**	.814**	-.058	.204	-.160
3.Right Eyebrow (ABS.)			.627**	.601**	.548**	.586**	.446**	.378**	.330*	.613**	.002	-.046	-.285*
4.Left Eyebrow (ABS.)				.661**	.504**	.410**	.309*	.147	.130	.428**	-.032	.019	-.092
5.Nasal Cavity (ABS.)					.840**	.538**	.471**	.388**	.334*	.688**	-.116	.129	-.206
6.Ridge of Nose (ABS.)						.443**	.307*	.525**	.484**	.662**	-.151	.055	-.315*
7.Right Eye (ABS.)							.683**	.406**	.382**	.704**	.143	.159	-.098
8.Left eye (ABS.)								.295*	.286*	.500**	.179	.045	.092
9.Outer lips (ABS.)									.960**	.756**	.093	.160	-.120
10.Inner lips (ABS.)										.716**	.113	.137	-.152
11.Face (ABS.)											.154	.223	-.124
12.Age												-.015	.395**
13.Sex													-.020
14.GAF													

Note: ABS.: Absolute Synchrony, **: $p < .01$, *: $p < .05$, +: $p < .010$, Sex (male = 1, female = 0), GAF: Global Assessment of Functioning

Table 7. Correlations among Therapeutic Alliance, Symmetrical Synchrony of Facial Expressions, and Complementary Synchrony of Facial Expressions

	1	2 (SYM.)	3 (SYM.)	4 (SYM.)	5 (SYM.)	6 (SYM.)	7 (SYM.)	8 (SYM.)	9	10	11
1.Therapeutic Alliance	-	.372**	.235	.328*	.182	.261	.258	.318*	-.173	-.240	-.037
2.Angry (COMP.)	.257	.488**	.594**	.680**	.673**	.760**	.497**	.746**	-.249	-.350**	-.087
3.Disgust (COMP.)	.188	.470**	-.072	.558**	.470**	.542**	.616**	.613**	-.098	-.251	-.053
4.Scared (COMP.)	.273*	.639**	.479**	.660**	.616**	.705**	.574**	.714**	-.147	-.166	.109
5.Happy (COMP.)	.278*	.279*	-.061	.252	.084	.728**	.420**	.731**	-.259	-.370**	.037
6.Sad (COMP.)	.312*	.648**	.304*	.646**	.524**	.667**	.394**	.656**	-.182	-.314*	-.050
7.Surprise (COMP.)	.026	.338*	.273*	.544**	.371**	.412**	.351**	.544**	-.194	-.152	-.074
8.Neutral (COMP.)	.260	.638**	.223	.629**	.430**	.774**	.238	.526**	-.171	-.370**	.035
9.Age	-.173	-.120	-.006	-.233	-.109	-.257	-.210	-.281*	-	-.015	.395**
10.Sex	-.240	-.134	.107	-.241	-.146	-.092	-.035	-.113	-.015	-	-.020
11.GAF	-.037	.117	.110	-.096	-.019	.067	-.165	-.006	.395**	-.020	-

Note: The upper triangle indicates symmetrical synchrony, whereas the lower triangle indicates complementary synchrony. The diagonal indicates the correlations between complementary and symmetrical synchrony. COMP.: Complementary synchrony, SYM.: Symmetrical synchrony, **: $p < .01$, *: $p < .05$, Sex (male = 1, female = 0), GAF: Global Assessment of Functioning

Table 8. Correlations of Therapeutic Alliance, Synchrony of Facial Expressions, and Synchrony of Facial Movements

	2	3	4	5	6	7	8	9	10	11	12	13
1.Therapeutic Alliance	.182	.328*	.278*	.273*	.285*	.331*	-.324*	-.325*	.042	.222	-.212	-.096
2.happy (SYM.)		.616**	.084	.620**	.880**	.679**	-.380**	-.272*	-.200	.001	-.385**	-.187
3.scared (SYM.)			.451**	.660**	.733**	.918**	-.363**	-.265	-.152	.043	-.346**	-.157
4.happy (COMP.)				.252	.547**	.390**	-.109	-.194	-.205	-.210	-.190	-.255
5.scared (COMP.)					.641**	.904**	-.295*	-.271*	-.066	.020	-.250	-.175
6.happy (ABS.)						.756**	-.371**	-.321*	-.266*	-.099	-.414**	-.278*
7.scared (ABS.)							-.363**	-.294*	-.122	.035	-.329*	-.182
8.right eye (SYM.)								.784**	.226	.023	.848**	.553**
9.left eye (SYM.)									.223	.239	.690**	.827**
10.right eye (COMP.)										.629**	.708**	.518**
11.left eye (COMP.)											.358**	.743**
12.right eye (ABS.)												.683**
13.left eye (ABS.)												

Note: COMP.: Complementary synchrony, SYM.: Symmetrical synchrony, ABS.: Absolute Synchrony, **: $p < .01$, *: $p < .05$,

Table 9. Hierarchical Regression Analysis on Therapeutic Alliance from Symmetrical and Complementary Synchrony

	model1		model2		model3	
Age	-.176		-.087		.021	
Sex	-.242	+	-.035		-.113	
Happy(Par.)			.369	*	.189	
Happy(Th.)			.060		.267	
Scared(Par.)			.167		.176	
Scared(Th.)			-.466	*	-.516	**
V. Right eye(Par.)			-.094		-.222	
V. Left eye (Par.)			.004		.161	
V. Right eye(Th.)[d]			-.526		-.608	
V. Left eye (Th.)			.158		.220	
SYM. Happy					-.167	
SYM. Scared					.393	
COMP. Happy					-.005	
COMP. Scared					-.056	
SYM. Right eye					.148	
SYM. Left eye					-.487	*
COMP. Right eye					-.092	
COMP. Left eye					.373	*
F	2.526[a]	+	2.358[b]	*	2.720[c]	**
adjusted R^2	.053		.201		.364	
R^2	.089		.349		.576	
ΔR^2	.089	+	.260	*	.227	*

Notes [a]: *df* = 2, 52; [b]: *df* = 10, 44, [c]: *df* = 18, 36. [d]: Volume of right eyes (Th.) had high variance inflation factors (Model2 = 8.460, Model3 = 14.120), so coefficients of volume of right eyes (Th.) were high but did not reach significant levels. Par.: Participant, Th.: Therapist, SYM.: Symmetrical synchrony, COMP.: Complementary synchrony, **: $p < .01$, *: $p < .05$, +: $p < .10$

Table 10. Hierarchical Regression Analysis on Therapeutic Alliance from Absolute Synchrony

	model1		model2		model3	
Age	-.176		-.087		-.018	
Sex	-.242	+	-.035		-.015	
Happy(Par.)			.369	*	.302	+
Happy(Th.)			.060		.229	
Scared(Par.)			.167		.102	
Scared(Th.)			-.466	*	-.458	*
V. right eye(Par.)			-.094		-.131	
V. left eye (Par.)			.004		.083	
V. right eye(Th.)[d]			-.526		-.476	
V. left eye (Th.)			.158		.157	
ABS. Happy					-.149	
ABS. Scared					.384	
ABS. Right eye					-.138	
ABS. Left eye					.059	
F	2.526[a]	+	2.358[b]	*	2.014[c]	*
adjusted R^2	.053		.201		.208	
R^2	.089		.349		.413	
ΔR^2	.089	+	.260	*	.065	

Notes [a]: *df* = 2, 52; [b]: *df* = 10, 44, [c]: *df* = 18, 36, [d]: Volume of right eyes (Th.) had high VIF (Model2 = 8.460, Model3 = 10.673); consequently, coefficients of volume of right eyes (Th.) were high but did not reach significant levels. Par.: Participant, Th.: Therapist, ABS.: Absolute Synchrony, **: $p < .01$, *: $p < .05$, +: $p < .10$