Brain Activity During Turn-Taking Using Virtual Characters: An fMRI Study on Humans Interacting with Virtual Characters[1]

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In this study, we examined turn-taking behavior by measuring brain activity using functional magnetic resonance imaging (fMRI). We developed virtual characters that exhibited turn-taking behavior. These characters displayed facial expressions that indicated a willingness to continue talking, and regulated its timing in conversational turn-taking. We then confirmed the validity of these behaviors through behavioral experiments that used a pseudo-conversation between these virtual characters and human participants. In addition, we conducted an fMRI experiment where the participants were required to read part of a scenario in a conversation with the character. The results showed that the insular cortex and the right superior temporal gyrus were significantly activated when the character behaved properly in turn-taking. These results suggest that the activation of the right superior temporal gyrus was related to mutual understanding. The insular cortex has been shown to be related to empathy in previous studies. Thus, turn-taking may have a significant role related to mutual understanding and empathy in conversation. Our experimental design and findings may provide an objective framework for virtual character design, and contribute to the study of human conversation.

1. Creation of the turn-taking scenarios and virtual character behavior

<**1・1**> The planned conversational turn-taking scenarios

Previous research has measured brain activity when hearing words which are “closely related” and “completely unrelated” to a previous word and when hearing sentences “for which the context is correct” and “for which the context is not correct.” Similarly, we created an “easy-to-continue” and a “difficult-to-continue” conversational turn-taking scenario and investigated brain activity by recording differences in the fMRI measurement results.

<**1・2**>Planning the conversational turn-taking scenarios

We assumed a conversation with three parties and developed the face-to-face system shown in Fig. 1.

Although turn-taking occurs with two people as well, conversation participants may begin speaking at the same time during turn-taking between three parties or more and so it is necessary for the conversation participants to attempt to judge and resolve who will continue the conversation [1][43]. As this study focuses on the continuation of conversation, we will use three party turn taking, which makes judgment and resolution for the continuation and maintenance of the conversation more essential.

As shown in Fig. 1, character A and character B were placed on the left and right of the screen and assumed conversation with the experiment participant who was in front of the display screen. The television production software TVML was used in creating the scenario [44]. TVML displays the virtual characters on the screen and their actions and speech can be controlled by a script (language). “Lip syncing,” in which the size of the mouth changes according to the volume of the synthesized speech (or speech file), was also implemented [45][46] using TVML to allow the face-to-face conversation to continue without noticeable discrepancies between the image of the mouth and the character’s speech [7]~[9].

Further, the following was designed for this experiment with consideration to the later brain activity measurement experiment.

(1) The fixed speaking order of the characters and the experiment participant (speaking order: character A, character B, experiment participant, character B again)

(2) The advance creation of the script (spoken words).

The characters spoke a dialogue created in advance. When it was the experiment participant’s turn to speak, their dialogue was presented onscreen as a caption and they read it aloud.

As the development and flow of conversation between people is usually unpredictable and difficult to control in an experiment, a virtual turn-taking situation was produced by determining the speaking order and dialogue of the characters and the experiment participant in order to control their actions.

An example of the flow of conversation is shown in Fig. 1. First, character A on the left says, “Have you finished your work for today?” (Fig. 1 (1)). In response, character B says, “Yes, I’ve finished my work for today” (Fig. 1 (2)). Next, a caption appears at the bottom of the screen. At this time, as shown in Fig. 1 (3), character A and character B look forward (they look at the experiment participant, or look at the camera, so to speak). The experiment participant reads the caption of “That’s good. You’ll go home early, won’t you?” as their own line, developing a pseudo-conversation. After this, character B’s response is “Yes, I want to go home early so that I can watch my favorite video” (Fig. 1 (4)). The final action of character B is an expression which matches any of the four previously mentioned categories: “Change,” “No change,” “Natural,” or “Delayed” (Table 1). The characters’ voices are human voices recorded in advance. Note that the voices were from the same person and it is thought that there is no difference in the impression from the voice (tone) in each experimental condition.

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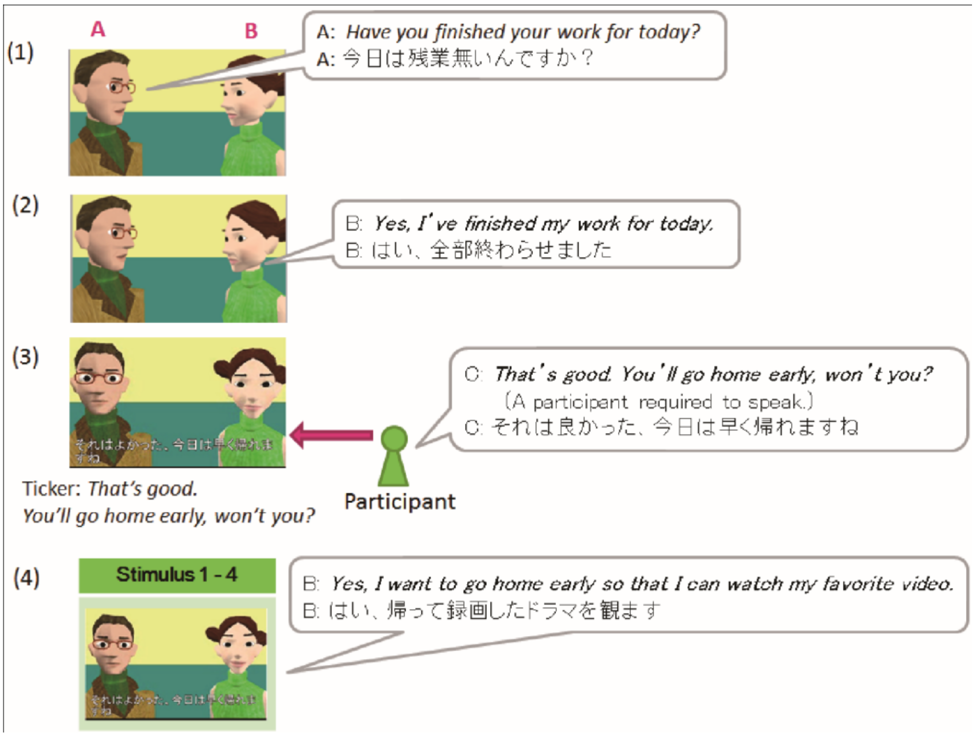

Fig.1.The Flow of Conversation by Virtual Characters and Participant.

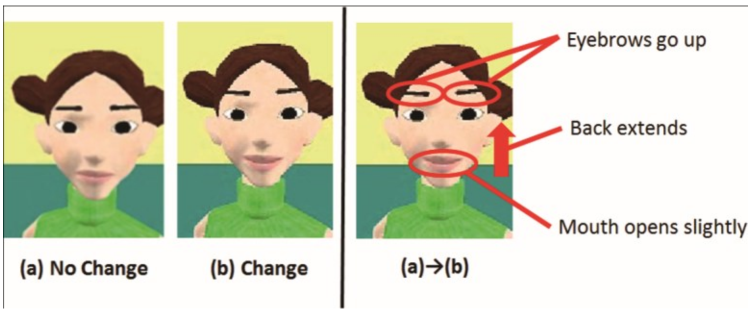

Fig.2. Changes in Facial Expression.

Table 1. Stimulus 1–4

	Stimulus 1	Stimulus 2	Stimulus 3	Stimulus 4
Motion	Change	Change	No Change	No Change
Timing	Natural	Delay	Natural	Delay

After the experiment participant spoke their line, the experimenter (author) would cause character B to say the line from Fig. 1 (4) by manually pressing a button on the keyboard while listening to the experiment participant speak. Note that the operation from the keyboard button pressed by the experimenter was remote and was not seen by the experiment participant. During the instruction beforehand, it was emphasized in the explanation that “the characters are moving in response to your (the experiment participant’s) voice.” Accordingly, it was believable that the experiment participant and characters were having a conversation.

<**1・2・1**> Investigation of behavior during conversational turn-taking

In this study, we focused on “change” and “speech timing” which are connected to the continuation of conversational turn-taking.

“Change” is the attitude displayed by the listener during turn-taking. Conversation participants anticipate who wants to speak and who wants to listen [2]. For the purpose of continuing a conversation, it is particularly important to display an attitude of wanting to speak [8]. For example, changes such as smiling or leaning forward indicate a desire to speak and lead to positively and actively progressing the conversation. Meanwhile, if one converses with no expression, this demonstrates that they do not really want to talk or continue the conversation which does not lead to a continued conversation.

"Speech timing" is the timing in which the next speaker begins speaking (the interval before they begin speaking). Nagaoka et al. noted that the interval while the speaker is switching has a major effect on the expression of specific emotions [(47)]. Further, Trimboli states that the interval changes depending on the type of conversation (cooperative conversation, confrontational conversation) [(48)]. Timing is one essential element composing conversation. Speaking with timing that smoothly advances the conversation with no discomfort leads to maintaining a conversation [(47)]. Meanwhile, leaving an interval after the previous speaking has finished before one begins speaking, or speaking while another is still speaking, do not lead to maintaining a conversation [(47)]. The following four behaviors were created based on the above investigations. Combinations of these behaviors compose experimental stimuli 1 through 4. Table 1 shows the combinations in experimental stimuli 1 through 4.

・"Change": Expression of a desire to speak. Can be understood as a desire to pleasantly continue conversation.

・"No Change": No facial expression. Can be understood as not really wanting to speak and not wanting to continue conversation.

・"Natural Speech Timing": Beginning to speak with appropriate timing (interval) to progress the conversation with no discomfort.

・"Delayed Speech Timing": Beginning to speak too long after the previous speaker has finished, making it difficult to progress the conversation.

<**1・2・2**> Implementation of conversational turn-taking behavior

The "Change" used in this experiment is based on previous research [(8)(49)] and consists of: (1) raising the eyebrows, (2) slight upward extension of the upper half of the body and the neck, and (3) raising the corners of the mouth (both ends). Fig. 2 demonstrates an example implemented with a character. Past research has verified that these changes are an expression of a desire to speak (an expression claiming the right to speak) [(8)].

In stimuli in which the "speech timing" was "Natural" (experimental stimuli 1 and 3), character B began speaking immediately after the participant finished speaking. When the speech timing was "delayed" (experimental stimuli 2 and 4), there was an interval (0.6 sec) between when the participant finished speaking and when character B began speaking. A value of 0.6 seconds was used as this is the technical limit for the facial CG synthesis to appear natural; any shorter than this and it will appear unnatural. Enomoto et al. report that turn-taking ceases to be smooth when an interval of one second or longer is left [(50)] and so an interval of 0.6 seconds is not too long. The experimenter controlled the speech timing of the characters ("Natural" or "Delayed") by pressing a button on the keyboard while listening to the participant speak.

2. Verification of the interpretation of behavior and conversation continuity by questionnaire

<**2・1**> Character behavior verification experiment

<**2・1・1**> Items assessed by the questionnaire

A questionnaire experiment was implemented to explore the interpretation of the experimental stimuli created. To select the items assessed by the questionnaire, an interview was carried out regarding the experimental stimuli in advance and six assessment items representing the characteristics of the experimental stimuli were selected ((a) Comfortable - Uncomfortable, (b) Natural tempo - Unnatural tempo, (c) Smooth - Rough, (d), Comfortable - Uncomfortable, (d) Standard - Strangeness, (f) Mutual Understanding - Misunderstanding). Each assessment item was assessed on five levels. Further, to explore differences in conversation continuity for each experimental stimulus, the items of "(g) Character's willingness to continue talking (whether the participant thinks the character on the right "wants to keep talking")" and "(h) Participant's willingness to continue talking (whether you feel, based on the words and actions of the character on the right, you "want to continue talking")" were created and explored. Responses to (g) and (h) were established as seven level assessments.

Experiment participants were asked to carry on a pseudo-conversation with the characters as shown in Fig. 1. It was conveyed to participants that: "this is a three-party conversation between you and the characters," "the characters will listen and respond to your voice," and "your dialogue will be shown as a caption, so please read it." Further, it was confirmed that the participants understood the flow of conversation from the practice beforehand. The characters' spoken lines were the same; only the non-verbal behaviors for experimental stimuli 1 through 4 were changed. Each execution of the questionnaire items and experimental stimuli used a random order.

<**2・1・2**> Experiment results

Respondents were university students. Assessment items (a) through (f) were answered by 17 individuals and (g) through (h) were answered by 19 individuals.

<**2・1・3**> Discussion of the questionnaire experiment

The results demonstrated that, compared to other stimuli, experimental stimulus 1 had significantly higher assessments for the survey items of "highly comfortable," "natural tempo," "smooth," "comfortable," "character's willingness to continue talking" and "participant's willingness to continue talking." Therefore, experimental stimulus 1 consisted of behavioral expression consistent with the realization of a continuous conversation. Meanwhile, compared to other stimuli, experimental stimulus 4 was lower on all assessed values: unnatural tempo, rough, uncomfortable, etc. and it is unlikely that this stimulus would encourage a continuous conversation. It is thought that the created behaviors themselves were natural, not strange, and there were no problems using these as experimental stimuli for turn-taking.

<**2・2**> Summary of the questionnaire experiment

From the above, it was found that experimental stimulus 1 included change and timing for the purpose of continuing a conversation, while experimental stimulus 4 included change and timing making it difficult to continue a conversation. As previously mentioned (section 2.1), in this study, we took fMRI measurements using experimental stimuli 1 and 4 to compare an "easy-to-continue" and a "difficult-to-continue" conversational scenario. Reference (5) notes that, in conversational turn-taking, conversation participants interpret intentions and behaviors (whether one wants to talk) from a combination of facial expressions and their timing to determine who should speak next. It can be said that conversational turn-taking behaviors are integrative and combine both change and expression timing. In order to identify the brain areas active during turn-taking, we attempted to find differences in brain activation between the two stimuli by selecting experimental stimulus 1, consisting of integrative turn-taking behavior, and experimental stimulus 4, consisting of the opposite, and taking fMRI measurements.

From the experiment results, the created behaviors are natural and there is no problem using them as experimental stimuli. From these findings, it was thought that, even if the behaviors are made by a digital character, conversational turn-taking plays its full role (effect) and we next proceeded to fMRI measurements.

3. fMRI measurements of conversational turn-taking with characters

<**3・1**> Experiment method

<**3・1・1**> Changes from the questionnaire experiment

Unlike the above-mentioned questionnaire, it was necessary here to get a sufficient number of scans for interpretation. Accordingly, the conversation topic was supplemented. The supplemented lines are shown in Appendix 1. Words and sentences were selected as much as possible so that each line would be the same length. Further, they were thoroughly screened in advance and authors and participants (not including fMRI experiment participants) removed or reworded sections that were difficult to hear, difficult to read aloud, or easily misread by the experiment participant. Additionally, in the experiment, the effect of an individual character's appearance was reduced by replacing the character with a different one after one topic of conversation was finished.

<**3・1・2**> Experiment participants

Experiment participants were eight university students (ages 20 to 23, average age 21.4; 4 male, 4 female). The experiment contents were approved by the ethical review board of the relevant facility (The Human Bioethical Review Board of Tokyo Denki University). The experiment objective, details, and warnings (risks, protection of personal information, etc.) were fully explained to the experiment participants using a similarly approved experiment explanation form and documents after which consent was obtained in writing.

<**3・1・3**> Experiment conditions

A 1.5T superconducting magnet MRI scanner (Stratis-II) (installed at the Tokyo Denki University Chiba New Town Campus) produced by Hitachi Medical Corporation was used. The experiment participant, lying on their side on the bed within the MRI machine, wore prism glasses to watch the image of the characters depicted on a screen located by their feet. Experiment participants could hear the character's voices through a pair of non-magnetic headphones and the participant's speech was conveyed to the experimenter using a non-magnetic microphone. As with the questionnaire experiment, the experimenter manually pressed buttons on a keyboard while listening to the experiment participant speak.

<**3・1・4**> Measurement method

Measurement used a block design which divided the various tasks and rests of the stimuli into fixed times. Fig. 4 shows the composition of one scan while Fig. 5 shows the tasks and rests in one session. During rests, a cross-shaped mark was presented in the center of the screen. Task stimuli were one topic from Fig. 1 (1) to (4). A sparse imaging method was used in which, after conversation on one topic, there was a two-second interval followed by one three-second scan [51]. The dialogue lines used in the experiment are shown in Appendix 1. To eliminate an effect due to presentation order, the lines were presented in random order during the task. During one task either eight scans using experimental stimulus 1, or eight scans using experimental stimulus 4 were completed. Including these tasks and rests, a total of 52 brain image scans were taken in one session. To reduce effects from presentation order, sessions which switched the tasks of experimental stimulus 1 and experimental stimulus 4 were also prepared, and three sessions were conducted with each participant. The total measurement time for all 3 sessions was approximately 45 minutes.

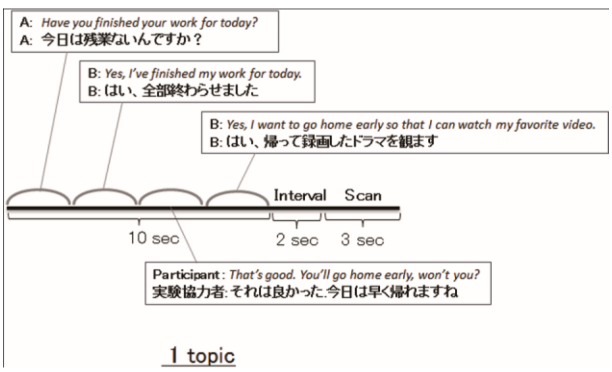

Fig.4. The composition of a topic (Utterances, an interval and a scan)

Fig.5. Structure of a session

Imaging conditions were as follows: FOV: 240mm × 240mm, TR/TE: 3000 / 50.5ms, Flip Angle: 90deg., slice thickness 4.0mm, space between slices 1.0mm. The EPI image Voxel size was 3.75 × 3.75 × 5.0 mm and the full width at half maximum (FWHM) was 10mm. Imaging was implemented in an Echo-Planar Imaging (EPI)-GE sequence.

<**3・1・5**> Analysis method

Significant signals were selected based on the intensity of the BOLD signals of the various tasks and rests. These were mapped onto the image of a standard brain to obtain a brain image of the experiment results. The analysis process was as follows: (1) Realignment: Correction of disparities caused by participant movement during the experiment. (2) Normalization: Converting the participant's brain to a standard brain (Talairach). (3) Smoothing: Smoothing noise included in the imaging and improving the S/N ratio. (4) Statistics: t-test for each Voxel. Analyses used the medical imaging analysis software SPM8[(52)]. Activation areas were sought through group analysis using the contrast image between the two conditions obtained for each participant. A 3D brain image indicating the hypothesized activation pattern with an SPM{Z}Map [(53)(54)] was created.

<**3・2**> Experiment results

Fig. 6 shows the images resulting from the experiment. Table 2 shows the areas activated when the activation data from experimental stimulus 4 tasks was subtracted from the activation data from experimental stimulus 1 tasks as well as the Brodmann area (BS), coordinates, and Z-Score (uncorrected $p < .001$).

The analysis results primarily demonstrated activation in the right cerebral hemisphere. Activation in the insula and superior temporal gyrus (STG) of the right brain were marked. Activation was also seen in the putamen, precentral gyrus, around Heschl's gyrus, and the cerebellum.

Table 2. Brain regions activated during turn-taking (uncorrected p < .001, k > 10, L=left, R=right, Stimulus 1 > Stimulus 4)

Region	Side	BA	x	y	z	Z-Score
Cerebellum	R	N/A	6	-42	-16	4.82
Cerebellum	L	N/A	-2	-36	-16	3.24
Insula	R	13	36	12	-6	4.69
STG	R	38	44	12	-12	3.37
Insula	R	13	44	-18	-4	4.14
Midbrain	L	N/A	-10	-16	-6	4.13
Insula	R	13	42	6	4	4.12
Insula	R	13	44	0	10	3.12
Putamen	R	N/A	26	-2	-2	4.02
Insula	R	13	40	-8	-8	3.54
Precentral gy.	R	6	56	0	8	3.89
Insula	R	13	40	-8	6	3.53
Heschl's gy.	R	41	34	-28	12	3.47
Putamen	R	N/A	30	-26	0	3.17

(STG=Superior Temporal Gyrus, gy.=gyrus)

4. Discussion and Conclusions

The measurement results demonstrated activation in the right STG. This activation is believed to correspond to the abovementioned results by Stolk et al. [(31)(32)]. The game from Stolk et al.'s experiment involved progression through turn-taking while understanding one's own and one's opponent's hand (game pieces), similar to the conversational turn-taking in which one interacted while understanding one's own words and the characters' behavior. When we look at the experiment by Stolk et al. and the present experiment together, it is implied that activation of the right STG is related to understanding the actions of the self and others. Different from the interactions between words or between sentences handled in past research, conversational turn-taking is an interaction accompanied by mutual understanding and it is possible that we were able to grasp that brain activity in this study.

Furthermore, significant activation was observed in the right insula in this experiment. In addition to reports that the insula is active during measurements related to taste[(55)~(57)], emotion, and facial expression, it is also reported to be involved when one is linking visual and auditory stimuli[(62)(63)], empathizing with another person's pain[(64)~(67)], seeking an indulgence[(68)(69)], or making a decision[(70)(71)]. There are also studies reporting that the insula is involved in speech[(72)]. However, the experimental stimuli for both conditions (experimental stimulus 1 and 4) in the present experiment included speech, and it is thought that the difference in insula activation due to speech was cancelled out when the difference between the two conditions was analyzed. Accordingly, it is unlikely that the insula activation detected in this study is related to speech.

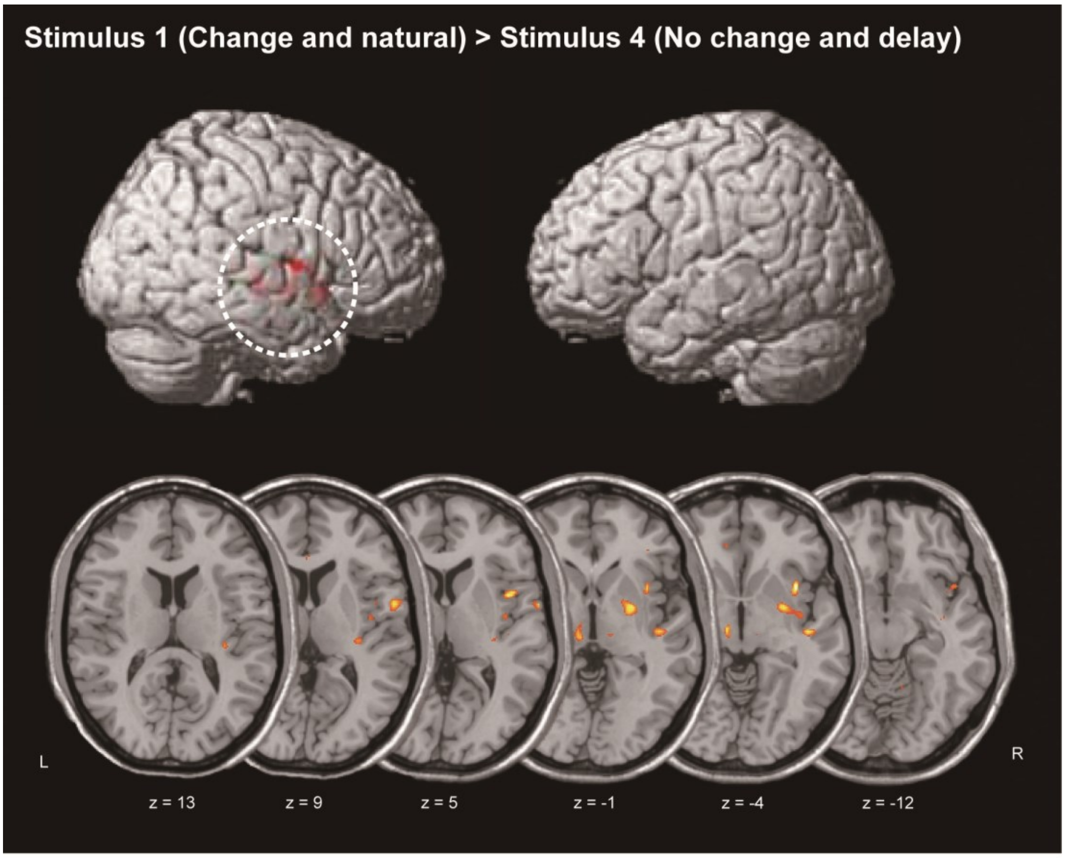

Fig.6.Brain areas activated during turn-taking (Stimulus 1 > Stimulus 4)

As mentioned above, conversational turn-taking is thought to be accompanied by mutual understanding, and it is possible that the insula activation in this study was related to empathy. Previous experiments related to empathy for pain included brain measurements when watching another person receive an electric shock(64)(65) and empathy can be thought of as feeling what another is feeling as though one was feeling it themselves. When continuing a conversation as well, it can be hypothesized that the participant felt something close to "empathy," in which they felt that "the character wants to continue talking" based on their conversational turn-taking behavior and therefore felt similarly themselves.

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