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Effects of Robot's Head movement and Timing in Human-Robot Interaction

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Effects of Robot's Head movement and Timing in Human-Robot Interaction

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Abstract

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In recent years, robots with artificial intelligence capabilities have become ubiquitous in our daily lives. As intelligent robots are interacting closely with humans, social abilities of robots are increasingly more important. In particular, nonverbal communication can enhance the efficient social interaction between human users and robots, but there are limitations of behavior expression. In this study, we investigated how minimal head movements of the robot influence human-robot interaction. We newly designed a robot which has a simple shaped body and minimal head movement mechanism. We conducted an experiment to examine participants' perception of robot's different head movements and timing. Participants were randomly assigned to one of three movement conditions, head nodding (A), head shaking (B) and head tilting (C). Each movement condition included two timing variables, prior head movement of utterance and simultaneous head movement with utterance. For all head movement conditions, participants' perception of anthropomorphism, animacy, likeability and intelligence were higher compared to non-movement (utterance only) condition. In terms of timing, when the robot performed head movement prior to utterance, perceived naturalness was rated higher than simultaneous head movement with utterance. The findings demonstrated that head movements of the robot positively affects user perception of the robot, and head movement prior to utterance can make human-robot conversation more natural. By implementation of head movement and movement timing, simple shaped robots can have better social interaction with humans.

Keywords: Head movement, Nonverbal communication, Human-robot interaction, HRI

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Chapter 1. Introduction

1.1. Motivation

Robots have become ubiquitous in our daily lives and social abilities of robots have become increasingly more important. Sophisticated social abilities of robots were developed with advances in artificial intelligence (Henschel et al., 2020). Interaction and collaboration with humans are the main activity of social robots (Gonzalez-Pacheco et al., 2013). Investigating human-robot interaction (HRI) is important to ensure robot's social norms and human user's expectations (Saunderson & Nejat, 2019).

Communicating with robots can be burdensome and unnatural (Scalise et al., 2018), and designing robots that can communicate naturally with humans is one of the challenges. One way to implement natural interaction between humans and robots is to incorporate nonverbal communications. Humans in all cultures use nonverbal communications to provide interaction signal, feedback and meta-communication (Mandal, 2014). In natural human conversation, we can easily find rich interaction of multiple verbal and nonverbal channels (Quek, 2002).

Over the last few decades, there have been significant designs and studies of humanoid robots for human-like interaction in order to make human-robot interaction more natural. Advances in artificial intelligence and engineering have made humanoid robots more human-like, but it is not a fundamental solution for natural HRI (Fox & Gambino, 2021). In addition, there are many non-humanoid robots that lack humanoid-form entirely as well as humanoid-features (Cha et al., 2018). Therefore, we should find modalities that can be implemented simply not only for humanoid robots but also for non-humanoid robots.

Because of the limitations of embodiment, It is often impossible to exploit straightforward nonverbal behaviors of humans (e.g., arm gesture, posture, facial expression, etc.) in non-humanoid robots (Cha et al., 2018). Also, behaviors of non-humanoid robots should be easily interpreted in a social context (Terada et al., 2007).

In this study, we focused on head movements of the robot. Previous research has shown that simple head movements for non-humanoid robots have a potential to enhance HRI (Zaga et al., 2017). In face-to-face communications, head pose and gesture provide visual grounding, turn-taking and answering yes or no (Morency et al., 2007). In order to focus on head movements of the robot, we newly designed a non-humanoid robot which has a simple shaped body and minimal head movement mechanism.

The objectives of this study are to explore how head movements of the robot affect user perception and to address the challenge of smooth HRI through timing adjustment of head movements of the robot in human-robot conversation.

1.2. Literature Review and Hypotheses

Face-to-Face interaction

Face-to-face interaction was defined as the reciprocal influence of individuals by Goffman (1959). The face is shared as a social value, and people get impressions and information about individuals through the face (Goffman, 1955). When people are engaged in face-to-face interaction, they can observe others directly and glean nonverbal cues (Zaharna, 2018). Through face-to-face communications, co-created meaning is amplified and individuals become part of something greater than themselves (Taylor, 2018). In face-to-face interaction, people use not only verbal but also nonverbal signals (e.g., eye gaze, head nod, etc.) in the grounding process to understand others (Clark, 1996; Nakano et al., 2003). Such signals are essential for the flow of meaning and emotional expression in face-to-face interaction (Turner, 2002). Previous research has shown that face-to-face interaction leads to more positive impressions of partners and greater self-other agreement, compared to online interaction (Okdie et al., 2011). Also, Behavior-awareness, in face-to-face environment, improves social interaction in group communication (DiMicco et al., 2007). Through face-to-face interaction, people observe non-verbal cues and understand each other better. Therefore, face-to-face environment in HRI should be considered when we design social robots for better social interaction.

Nonverbal communications

Nonverbal behaviors that convey certain meaning to observers are self-presentational (Goffman, 1959; Bella, 1992). Nonverbal behaviors carry a significant portion of the social meaning and emotional expression in face-to-face interchanges (Birdwhistell, 1952; Burgoon et al, 2011). A large part of initial assessment is visually observed through nonverbal expression (Ruesch & Kees, 1974). Nonverbal behaviors, such as head movements and gaze, can increase turn transition speed (Sriver et al 2009). In addition, nonverbal communications can maintain fluency of communication (Jokinen, 2009) and can define social relationships, such as who we are and how we are related (Burgoon & Hale, 1984; Okon, 2011). According to Phutela (2015), when nonverbal communication conflicts with verbal communication, individuals tend to rely on nonverbal communication. Nonverbal communication skills are an essential part of social competence in our daily lives and help people understand social context (Knapp et al., 2013).

Gestures

Gestures play a variety of roles in human-human conversation. It can reduce cognitive burden and provide a route to access new thoughts (Goldin-Meadow, 1999) and can help specify how verbal expression will be interpreted (Quek, 2002; Kita, 2009). People express emotions and meanings to observers through gestures (Mead & Schubert, 1934). Gesture and speech are linked internally and share a computational stage (McNeill, 1985).

In human-robot conversation, gestures of robots also play various roles similar to gestures of human-human conversation. In the previous study, participants felt more social interaction, enjoyment and engagement when the robot had gestures compared to participants in the no-gesture condition of the robot (Kim et al., 2013). Another study showed that people paid attention longer and had more confidence when the robot had gestures compared to audio only condition (Bremner et al., 2011). Another study has shown that nonverbal gestures of robots positively affect task efficiency through emotional expression (Yang & Williams, 2021). The other study reported that nonverbal behaviors of robots, such as head movements and eye movements, were significantly preferred than stationary robots (Zinina et al., 2020). These previous researches demonstrated that nonverbal gestures can enhance interaction between humans and robots.

Nonverbal expression in non-humanoid robot

It is difficult for non-humanoid robots to exploit straightforward expression of human behaviors due to limitations in behavioral expression (Cha et al., 2018). Despite the limitations of behavioral expression, previous studies have shown the potential for emotional expression in non-humanoid robots (Novikova & Watts, 2014; Law et al., 2020). In addition, previous research suggested that it is important to recognize non-humanoid robots as intentional existences for smooth communication between humans and non-humanoids (Terada et al., 2007). Examples of anthropomorphic non-humanoids can be found in animation films. A notable example is the Pixar lamp, Luxo Jr. by Pixar animation studio (1986), well known as used in the studio production logo. The Pixar lamp showed sophisticated expressions with simple mechanical structure (e.g., tilting lamp head) in animation. In this study, we also used the simple mechanism of the robot to represent the robot's head movements. These minimized movements may help convey nonverbal expression at the limits of implementation.

Anthropomorphism

Anthropomorphism is observer dependent (Duffy, 2002). Human-like form and function of robots have positive effects on the interaction between humans and robots (Eyssel et al, 2010). Also anthropomorphic movements can be more natural and thus more effective in HRI (Fink, 2012). Anthropomorphism provides the features of social engagement for a machine (Duffy, 2003).

However, according to the theory “Uncanny valley” (Mori, 2012), affinity for the robot can be decreased, unlike increasing human likeness. Creating a safe level of affinity through a balance of anthropomorphic features may be optimal (Duffy, 2003; Mori, 2012). Anthropomorphism is not just affected by physical appearance, and building artificial human-form is not the ideal for machines (Duffy, 2002; Złotowski, 2015). Anthropomorphism is basically for the social interaction between humans and robots.

Head movement

Head pose and gesture offer grounding cues, during face-to-face communication in human interaction (Morency et al., 2005). Head movement is used not only for taking of speaking turn (Duncan, 1972) but also for back-channel behavior (Yngve, 1970). Head movements (e.g., nodding, turning, pointing, shaking, etc.) are elements of turn-taking signals (Duncan, 1972). Back-channel behaviors are the listener's response such as "mm-hm," and "yeah," and head movements, such as nods and shakes (Yngve, 1970; Duncan, 1974). It can imply the listener's attention to the speaker and can give impressions of avoiding speaking turn as well (Duncan, 1974). Head movement is a very common and basic behavior of human communications and is observed by both speakers and listeners (Heylen, 2009). It has typical kinetic patterns and brings interactive functions (McClave, 1999; Heylen, 2006).

Head nod, vertically up-and-down movements, is used for affirmation in many cultures (McClave, 1999; Heylen, 2006). Head shake, horizontally side-to-side sweeps, is generally used to signal negation (McClave, 1999; Kendon, 2002; Heylen, 2006). Lateral head tilt is used to express uncertainty about an answer.

Head movement in HRI

In interaction between humans and robots, head movement of robots can enhance user perception of likeability (Salem et al., 2013; Zaga et al., 2017; Osugi, & Kawahara, 2018), animacy (Zaga et al., 2017), naturalness (Liu et al., 2013) and anthropomorphism (Kim et al., 2022; Salem et al., 2013) of robots. Anthropomorphism (Natarajan & Gombolay, 2020) and animacy (Bartneck et al., 2009a) are significant factors to enhance HRI. Also, Animacy has significant correlation with perceived intelligence of robots (Bartneck et al., 2009a).

In this study, we explored the effects of robot's head movements on user perception of anthropomorphism, animacy, likeability and intelligence by comparing them with three head movement conditions: nodding (A), shaking (B) and tilting (C).

Based on previous research finding that simple head movements of non-humanoid robot showed potential to enhance HRI (Zaga et al., 2017), we hypothesized that minimal head movements of non-humanoid robots would positively affect user perception of anthropomorphism, animacy, likeability and intelligence of robots.

H1. Minimal head movements of the non-humanoid robot will increase the participants' perception of anthropomorphism (H1a), animacy (H1b), likeability (H1c) and intelligence (H1d) of the robot.

Turn-taking

Turn-taking is the concept of fundamental speech-exchange system (Sacks et al., 1974). It is not just a mechanical procedure, but also has social meanings and relationships (Coates, 1994; Wiemann & Knapp, 2017). Both speakers and listeners focus on the partner's signals and engage in Turn management (Jokinen et al, 2013).

In human-human conversation, Turn-taking transitions, meaning speech-exchange from the prior speaker to the next speaker, are commonly tightly synchronized (Wilson & Wilson, 2005). Turn-taking gaps in human conversation average around 200 ms (Stivers et al., 2009; Levinson & Torreira, 2015) and are not recognized as silent gaps (Torreira et al., 2016). However, in human-robot conversation, there is long response delay problem (such as 2 seconds) and it brings about uncomfortable silence in turn-taking (Skantze, 2021).

Timing of Movement

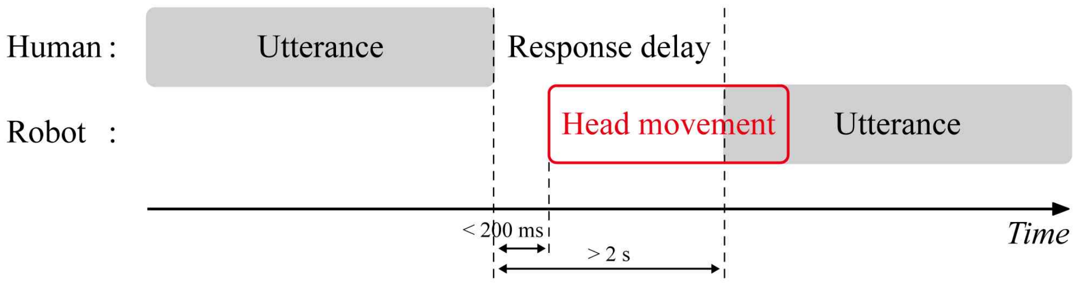
According to Hadar et al., (1984), head posture shifts usually begin prior to speech onset and indicate beginning to speak. Through prior head movements of speech, listeners can claim their speaking turn and prepare to speak (Duncan, 1972; Hadar et al., 1984; Harrigan, 1985). In addition, Dittman & Llewellyn (1972) reported that head movements tend to follow a hesitation pause prior to the beginning of speech. Summarizing these studies, head movements prior to speech play a variety of roles, such as turn-requesting, indicating to speak and preparing speech. Also head movements in vocal hesitations are common in human conversation.

In human-robot conversation, robot's head movements prior to utterance may also play roles similar to human-human conversation. We hypothesized that head movements prior to utterance (Figure 1) may reduce the problem of long response delays and show higher perceived naturalness than simultaneous head movement with utterance.

H2. Head movements prior to utterance will show higher perceived naturalness rating than simultaneous head movement with utterance.

Figure 1.

An example of prior head movement of utterance



Previous research has shown that likeability of robots consistently improves along with the naturalness of the synthesized voice (Baird et al., 2018). Also, another previous research suggested a strong correlation between perceived intelligence and naturalness (Barchard et al., 2020). We expected that perceived naturalness of head movements may be positively correlated with likeability and perceived intelligence.

H2-1. Perceived naturalness may be positively correlated with likeability (H2-1a) and perceived intelligence (H2-1b) of the robot.

1.3. Purpose of Study

The current study investigated how head movements of the robot enhance HRI. In specific, we investigated the effects of head movements and timing of movements in human-robot conversation. We conducted the experiment using a newly designed robot which has a simple shaped body and minimal head movement mechanism in order to investigate the effects of head movements on user perception of anthropomorphism, animacy, likeability, intelligence and naturalness of the robot.

There were three head movement conditions, nodding (A), shaking (B) and tilting (C), and two timing conditions, prior head movement of utterance and simultaneous head movement with utterance. Dependent variables were participants' perception of anthropomorphism (H1a), animacy (H1b), likeability (H1c), intelligence (H1d) and naturalness (H2). We also investigated the correlations between dependent variables, between perceived naturalness, likeability (H2-1a) and perceived intelligence (H2-1b). The goal of this study was to explore how head movements and timing of movements affect user perception of the robot.

Chapter 2. Experiment

2.1. Methods

Participants

A total of 90 participants (57 male, 33 female) with a mean age of 31.39 years (SD=3.48, range 24-38) were recruited. None of the participants were visually or hearing impaired. On average, participants spent a total of 12.4 minutes (SD=1.66, range 9-15), 3.5 minutes (SD=.50, range 3-4) on the actual task and 8.9 minutes (SD=1.65, range5-11) on the questionnaire. This study received prior approval from the Institutional Review Board of Seoul National University.

Design

We investigated how robot's head movements affect participants' perception of the robot in human-robot conversation. There were three movement conditions, nodding, shaking and tilting, and two timing conditions, prior head movement of utterance and simultaneous head movement with utterance.

Each participant was randomly assigned to one of three head movement conditions: nodding (A), shaking (B) and tilting (C). Participants were divided into 30 people per each movement condition. For each movement condition, conversation scripts were prepared according to the representative meanings of the robot's movements, such as affirmation of head nodding, negation of head shaking, and uncertainty of head tilting.

Each movement condition included two timing variables: prior head movement of utterance and simultaneous head movement with utterance. In prior head movement of utterance condition, the robot performed head movement within 200 ms and utterance in 2 s after the participant finished speaking. In simultaneous head movement of utterance condition, the robot simultaneously performed both head movement and utterance in 2 s after the participant finished speaking. Participants in each movement condition were divided into 15 participants per each timing condition. The number of participants for each condition was shown in Table 1.

Table 1.

Design of the experiment

Robot's response	*N*	Conditions		
		Movement	Timing	*N*
A *(Affirmation)*	*30*	Non-movement *(Control)*		
		Head nodding *(Treatment)*	AP *(Prior)*	15
			AS *(Simultaneous)*	15
B *(Negation)*	*30*	Non-movement *(Control)*		
		Head shaking *(Treatment)*	BP *(Prior)*	15
			BS *(Simultaneous)*	15
C *(Uncertainty)*	*30*	Non-movement *(Control)*		
		Head tilting *(Treatment)*	CP *(Prior)*	15
			CS *(Simultaneous)*	15

Procedure

After participants signed the consent form to participate, They were informed about the general procedure of the experiment and given an example of the conversation script that can be used when talking to the robot. In the conversation script, for head nodding movement (A), when a participant said to the robot, “Hey robot, I would like to set an alarm.”, the robot responded with a meaning of affirmation by saying “Ok, What time would you like?”. In case of shaking movement (B), when a participant said to the robot, “Hey robot, tell me my account password.”, the robot responded with a meaning of negation by saying “Sorry, it is impossible. Do you need anything else?”. For tilting movement (C), when a participant said to the robot, “Hey robot, I need to book a train ticket to Seoul.”, the robot responded with a meaning of uncertainty by saying “I didn't hear you. Can you use some other words?”.

Participants were randomly assigned to one of three movement conditions and asked to have a conversation with the robot on the screen (Figure 2). They talked to the robot according to the script and received the response from the robot. The conversation was conducted twice. In the first conversation, the robot responded with only utterance (non-movement condition). In the second conversation, the robot responded with both head movement and utterance (head movement condition). Questionnaires followed each conversation. At the end of each conversation, participants were asked to answer the questionnaire.

Figure 2.

Conversation simulation using 75-inch monitor in the experiment

Materials

In order to focus on head movement, we newly designed a non-humanoid robot which has a simple shaped body and minimal head movement mechanism in three-axis: x (pitch), y (roll) and z (yaw). Figure 3 presented the robot design. This mechanism allows the robot to perform three types of head movements (Figure 4). The dimension of the robot is 445 mm in height, 200 mm in width, 245 mm in depth and a circular shaped head is 200 mm in diameter.

In the experiment, the robot performed three types of head movements according to predefined scenarios. Each movement was actuated to represent each movement with 3D computer simulations. We rendered each 10 seconds animation, at 30 frames per second (fps), using Keyshot, 3D rendering software. Then we added the robot's voices, created with Text-To-Speech (TTS), and matched the audio and video using Adobe Premiere Pro software. After several pilot tests, all types of the robot's response conditions, 3 (movements) × 2 (timings), were prepared as videos.

Figure 3.

Isometric drawing of the robot design and mechanism

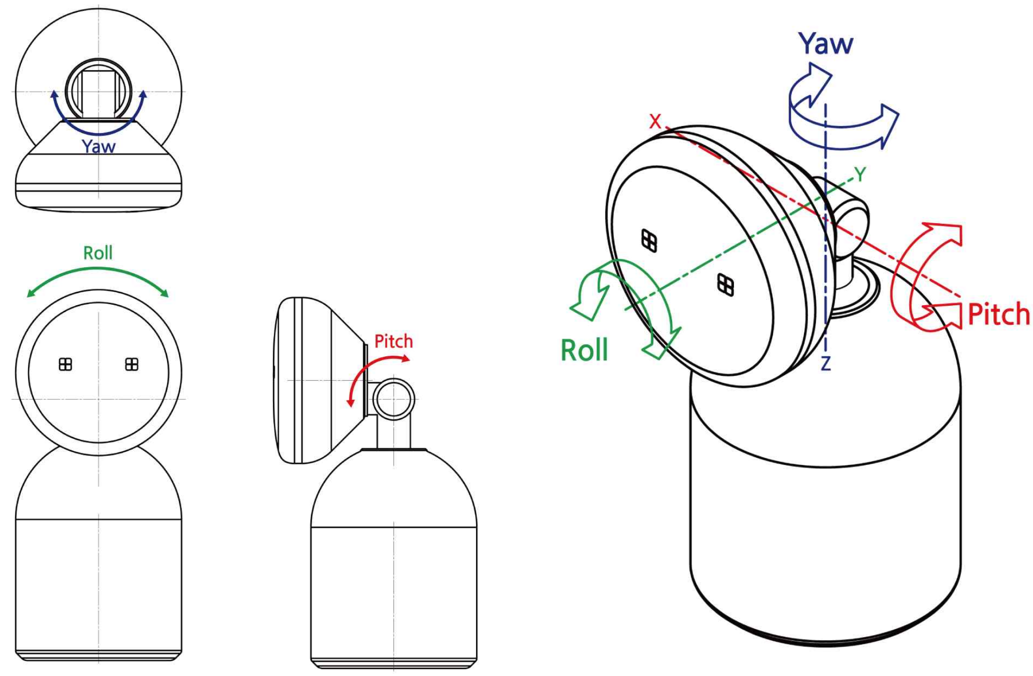
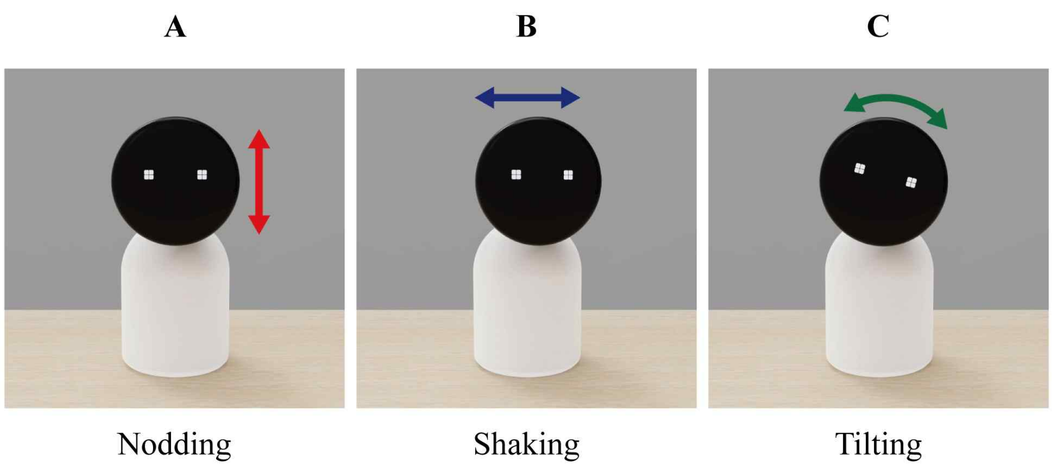


Figure 4.

Three types of head movements in the experiment



Anthropomorphism

We used the Godspeed questionnaire (Bartneck et al., 2009b) to measure participants' perception of anthropomorphism of the robot. Anthropomorphism refers to human characteristics of non-human things (Bartneck et al., 2009b). It is the significant factor in predicting trust of robots (Natarajan & Gombolay, 2020) and influence users' intention to use robots (Blut et al., 2021).

Animacy

We used the Godspeed questionnaire (Bartneck et al., 2009b) to measure participants' perception of animacy of the robot. Animacy refers to how users perceive animate and life-like movement (Bartneck et al., 2009b).

Likeability

We used the Godspeed questionnaire (Bartneck et al., 2009b) to measure participants' perception of likeability of the robot. This concept is to measure the degree of positive impressions of robots.

Perceived intelligence

We used the Godspeed questionnaire (Bartneck et al., 2009b) to measure perceived intelligence of the robot. It is a concept of how robots were perceived as smart and intelligent.

Perceived naturalness

In order to investigate how participants perceived naturalness according to the robot’s head movement, The degree of perceived naturalness was measured on a 5-point Likert scale by referring to previous study (Liu et al., 2012).

2.2. Results

Manipulation check

Manipulation checks of each type of head movements (treatment) were analyzed using the one-sample t-test. We measured the participants' perception rating of each type of head movements on a 5-point Likert scale: 5="strong" to 1="weak". The result provided that the robot had significantly different types of head movement conditions, nodding (A) ($T(29)=26.49$, $P<.001$, $d=.38$), shaking (B) ($T(29)=26.49$, $P<.001$, $d=.38$) and tilting (C) ($T(29)=29.57$, $P<.001$, $d=.35$). Means and standard deviations of result were nodding (A) ($M=4.83$, $SD.38$), shaking (B) ($M=4.83$, $SD=.38$) and tilting (C) ($M=4.87$, $SD=.35$).

Reliability

We calculated Cronbach's alpha to check the internal consistency of the participants' responses to anthropomorphism, animacy, likeability and perceived intelligence. Results showed that all of the measures were at acceptable levels. Cronbach alpha values for each measure in the experiment were presented in Table 2.

Table 2.

Internal consistency of measures in the experiment

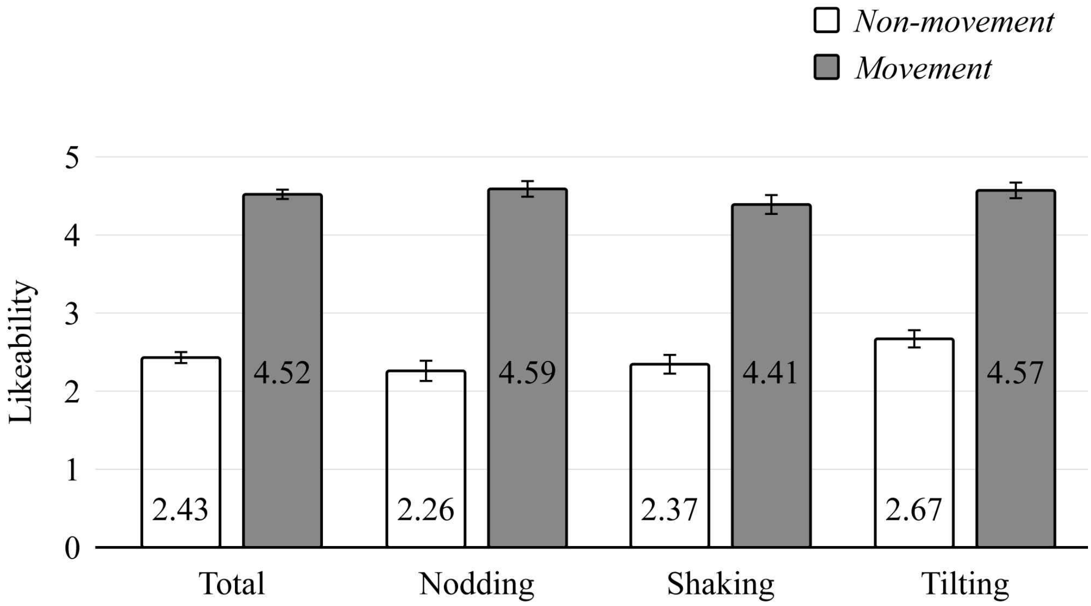
Measure	Number of items	Cronbach's α
Anthropomorphism	5	.97
Animacy	6	.98
Likeability	5	.95
Perceived intelligence	5	.95

Head movement

We investigated whether head movements of the robot affect participants' perception of the robot, using within-subjects t-test: non-movement (control) vs. head movement (treatment). The total head movement, including nodding (A), shaking (B) and tilting (C), had a statistically significant effect on likeability ($t(89)=21.92$, $p<.001$, $d=.90$). We found that when the robot performed head movements in conversation, likeability was higher compared to non-movement condition. Figure 5 showed that likeability increased in all types of head movements, nodding, shaking and tilting. It is revealed that robot's head movements lead to positive impressions of the robot in HRI.

Figure 5.

Mean likeability scores in the experiment



For all types of head movement, Anthropomorphism (t(89)=47.22, p<.001, d=.64), animacy (t(89)=57.81, p<.001, d=.54) and perceived intelligence (t(89)=21.78, p<.001, d=.88) of the robot also showed significant differences between head movement and non-movement conditions. Total head movement (M=4.50, SD=.44) had higher anthropomorphism rating than non-movement (M=1.34, SD=.42) of the robot. For animacy, total head movement (M=4.69, SD=.37) was rated higher than non-movement (M=1.43, SD=.40). Total head movement (M=4.52, SD=.60) had higher rating of likeability than non-movement (M=2.43, SD=.66). For perceived intelligence, total head movement (M=4.40, SD=.61) had higher rating than non-movement (M=2.39, SD=.60).

The results showed that all types of head movements of the robot significantly increased participants' perception of anthropomorphism, animacy, likeability and perceived intelligence. Means and standard deviations of variables in the experiment were shown in Table 3.

Table 3.

Means and standard deviations in the experiment

Robot's response	Movement	Anthropo-morphism	Animacy	Likeability	Perceived intelligence
		Mean (SD)	*Mean (SD)*	*Mean (SD)*	*Mean (SD)*
Affirmation	Head nodding	4.47 (0.46)	4.69 (0.41)	4.59 (0.56)	4.45 (0.59)
	Non-movement	1.33 (0.52)	1.40 (0.46)	2.26 (0.71)	2.28 (0.69)
Negation	Head shaking	4.48 (0.40)	4.73 (0.31)	4.41 (0.67)	4.29 (0.69)
	Non-movement	1.25 (0.29)	1.37 (0.29)	2.37 (0.63)	2.25 (0.49)
Uncertainty	Head tilting	4.56 (0.46)	4.64 (0.38)	4.57 (0.57)	4.47 (0.55)
	Non-movement	1.43 (0.40)	1.51 (0.44)	2.67 (0.58)	2.63 (0.55)
Total	Head movement	4.50 (0.44)	4.69 (0.37)	4.52 (0.60)	4.40 (0.61)
	Non-movement	1.34 (0.42)	1.43 (0.40)	2.43 (0.66)	2.39 (0.60)

Nodding

A within-subjects t-test revealed that the head nodding movement had statistically significant effects on the participants' perception of anthropomorphism ($t(29)=23.75$, $p<.001$, $d=.72$), animacy ($t(29)=30.76$, $p<.001$, $d=.59$), likeability ($t(29)=12.96$, $p<.001$, $d=.98$) and intelligence ($t(29)=11.89$, $p<.001$, $d=1.01$) of the robot.

Head nodding movement ($M=4.47$, $SD=.46$) had higher anthropomorphism rating than non-movement ($M=1.33$, $SD=.52$) of the robot. For animacy, head nodding movement ($M=4.69$, $SD=.41$) was rated higher than non-movement ($M=1.40$, $SD=.46$). Head nodding movement ($M=4.59$, $SD=.56$) had higher rating of likeability than non-movement ($M=2.26$, $SD=.71$). For perceived intelligence, head nodding movement ($M=4.45$, $SD=.59$) had higher rating than non-movement ($M=2.28$, $SD=.69$). The result showed that the head nodding movement significantly increased participants' perception of anthropomorphism, animacy, likeability and perceived intelligence.

Shaking

A within-subjects t-test revealed that the head shaking movement had statistically significant effects on the participants' perception of anthropomorphism ($t(29)=29.68$, $p<.001$, $d=.60$), animacy ($t(29)=41.63$, $p<.001$, $d=.44$), likeability ($t(29)=12.89$, $p<.001$, $d=.87$) and intelligence ($t(29)=14.74$, $p<.001$, $d=.76$) of the robot.

Head shaking movement ($M=4.48$, $SD=.40$) had higher anthropomorphism rating than non-movement ($M=1.25$, $SD=.29$) of the robot. For animacy, head shaking movement ($M=4.73$, $SD=.31$) was rated higher than non-movement ($M=1.37$, $SD=.29$). Head shaking movement ($M=4.41$, $SD=.67$) had higher rating of likeability than non-movement ($M=2.37$, $SD=.63$). For perceived intelligence, head shaking movement ($M=4.29$, $SD=.69$) had higher rating than non-movement ($M=2.25$, $SD=.49$). The result showed that the head shaking movement significantly increased participants' perception of anthropomorphisms, animacy, likeability and perceived intelligence.

Tilting

A within-subjects t-test revealed that the head tilting movement had statistically significant effects on the participants' perception of anthropomorphism ($t(29)=28.73$, $p<.001$, $d=.60$), animacy ($t(29)=30.66$, $p<.001$, $d=.56$), likeability ($t(29)=12.48$, $p<.001$, $d=.84$) and intelligence ($t(29)=11.76$, $p<.001$, $d=.85$) of the robot.

Head tilting movement ($M=4.56$, $SD=.46$) had higher anthropomorphism rating than non-movement ($M=1.43$, $SD=.40$) of the robot. For animacy, head tilting movement ($M=4.64$, $SD=.38$) was rated higher than non-movement ($M=1.51$, $SD=.44$). Head tilting movement ($M=4.57$, $SD=.57$) had higher rating of likeability than non-movement ($M=2.67$, $SD=.58$). For perceived intelligence, head tilting movement (M=4.47, SD=.55) had higher rating than non-movement (M=2.63, SD=.55). The result showed that the head tilting movement significantly increased participants' perception of anthropomorphism, animacy, likeability and perceived intelligence.

Timing of the head movement

A between-subjects t-test was conducted in order to examine the effects of timing adjustment of head movement: prior head movement of utterance vs. simultaneous head movement with utterance. Timing adjustment of total head movements including nodding, shaking and tilting showed a significant effect on perceived naturalness ($t(69.72)=4.55$, $p<.001$, $d=.58$), with that prior head movement of utterance (M=4.80, SD=.40) was rated higher than simultaneous head movement with utterance (M=4.24, SD=.71).

The head shaking movement prior to utterance was statistically significant ($t(23.21)=4.89$, $p<.001$, $d=.56$). However, both head nodding ($t(28)=1.56$, $p=0.13$, $d=.47$) and tilting ($t(28)=1.83$, $p=.08$, $d=.60$) movements prior to utterance were not statistically significant, but they also showed positive effects on perceived naturalness.

Prior head nodding movement of utterance (M=4.80, SD=.41) had higher perceived naturalness than simultaneous head nodding movement with utterance (M=4.53, SD=.52). Prior head shaking movement of utterance (M=4.80, SD=.41) had higher perceived naturalness than simultaneous head shaking movement with utterance (M=3.80, SD=.68). Prior head tilting movement of utterance (M=4.80, SD=.41) had higher perceived naturalness than simultaneous head tilting movement with utterance (M=4.40, SD=.74) (Table 4).

Table 4.

Means and standard deviations of timing variables in the experiment

Head movement	Prior movement of utterance	Simultaneous movement with utterance
	Mean *(SD)*	*Mean* *(SD)*
Head nodding	4.80 (.41)	4.53 (.52)
Head shaking	4.80 (.41)	3.80 (.68)
Head tilting	4.80 (.41)	4.40 (.74)
Total	4.80 (.40)	4.24 (.71)

Correlations with perceived naturalness

To examine how perceived naturalness is related to the likeability and perceived intelligence of the robot, we measured the correlations between them. Table 5 showed the significantly positive correlations between perceived naturalness and other variables, likeability and perceived intelligence.

Table 5.

Correlations between perceived naturalness and other variables

Variable	Perceived naturalness	Likeability	Perceived intelligence
Perceived naturalness	1.00		
Likeability	.47**	1.00	
Perceived intelligence	.53**	.78**	1.00

$^{**}p<.01$.

There were the positive correlation (R^2=0.22, $p<.01$) between perceived naturalness and likeability of the robot (figure 6) and the positive correlation (R^2=0.28, $p<.01$) between perceived naturalness and perceived intelligence of the robot (figure 7).

Figure 6.

Correlation between perceived naturalness and likeability

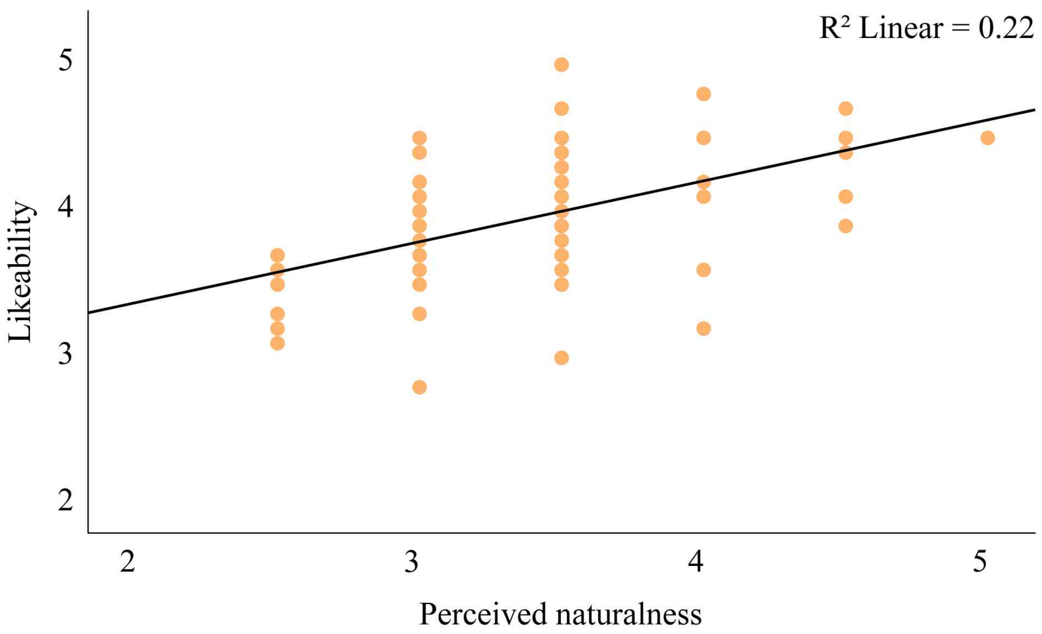
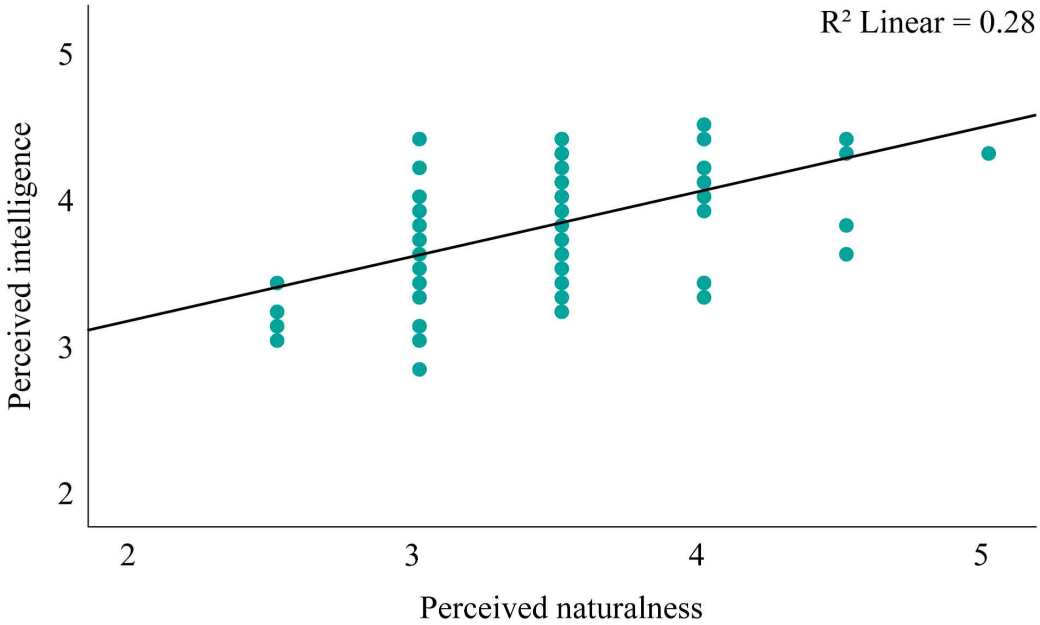


Figure 7.

Correlation between perceived naturalness and perceived intelligence



2.3. Discussion

The results of the experiment showed that head movements of the robot significantly affected user perception of HRI. Participants felt more anthropomorphism (H1a), animacy (H1b), likeability (H1c) and perceived intelligence (H1d) of the robot when the robot had the head movement condition compared to the non-movement (utterance only) condition.

In terms of anthropomorphism (H1a) and animacy (H1b), we observed that all types of head movements, nodding (A), shaking (B) and tilting (C), strongly affect anthropomorphism ($t(89)=47.22$, $p<.001$, $d=.64$) and animacy ($t(89)=57.81$, $p<.001$, $d=.54$). It may be because head movements have an impact on focusing attention and meaning of answering yes or no.

In terms of likeability (H1c) and perceived intelligence (H1d), there were also significant differences between all types of head movements and non-movement for Likeability ($t(89)=21.92$, $p<.001$, $d=.90$) and perceived intelligence ($t(89)=21.78$, $p<.001$, $d=.88$). These results revealed that head movements can make positive and smart-looking impressions.

The head movement prior to utterance had a significant effect on the perceived naturalness in human-robot conversation (H2). We observed positive perceived naturalness rating with the robot's prior head movement of utterance ($t(69.72)=4.55$, $p<.001$, $d=.58$) compared to simultaneous head movement with utterance. This suggested that prior head movement of utterance can reduce the problem of long response delays between utterances.

In addition, the perceived naturalness had significant correlations with likeability (H2-1a) and perceived intelligence (H2-1b). In particular, likeability of robots is affected by different variables at the same time (Zhong et al., 2022). These results supported that perceived naturalness is one of main variables determining likeability of robots, and naturalness of robot’s head movement is related to smart-looking impression.

Chapter 3. Conclusion

In the experiment, we hypothesized that head movements positively affect participants' perception of the robot. The results supported that. We manipulated three types of head movements, head nodding (A), head shaking (B) and head tilting (C), in order to investigate different types of head movements. In all types of head movements, when the robot performed head movement, participants' perception of anthropomorphism, animacy, likeability and intelligence were higher than non-movement (utterance only) condition.

For head movement timing, we expected that head movement prior to utterance may show higher perceived naturalness rating than simultaneous head movement with utterance. The results supported that. There were positive increases of perceived naturalness rating in prior head movement of utterance condition. Also, we hypothesized that perceived naturalness may be positively correlated with likeability and perceived intelligence. The results revealed that perceived naturalness had significant correlations with likeability and perceived intelligence.

In summary, first, robot's head movement increased participants' perception of anthropomorphism, animacy, likeability and perceived intelligence of the robot compared to non-movement condition. Second, head movement prior to utterance had a positive effect on perceived naturalness. Third, perceived naturalness had positive correlations with likeability and perceived intelligence of the robot.

The results of this experiment suggested that head movement can enhance HRI, and head movement prior to utterance can make human-robot conversation more natural. In conclusion, robot's head movements such as nodding, shaking and tilting can play significant roles in HRI and timing adjustment of the movement is an important part for designing and studying HRI.

Chapter 4. General Discussion

4.1. Theoretical Implications

Previous studies have revealed effects of nonverbal expression in HRI and studied not only head movements but also other various expressions (e.g., posture, arm gesture, facial expression, etc.). Previous studies have investigated human-like movements in humanoid robots. However, there are limitations of behavioral expression in non-humanoid robots. A few studies have investigated effects of minimized nonverbal expression such as eye gazing of non-humanoid robots (Zaga et al., 2017) and showed the potential of minimal gestures in interaction between humans and non-humanoid robots.

In this study, we focused on head movement of the robot as a minimal nonverbal expression which can be easily implemented in not only non-humanoid but also humanoid robots. Our findings demonstrated effects of minimal head movements on user perception in HRI. It may be useful to develop robotic mechanisms to enhance social abilities of robots.

Also our study revealed that head movement prior to utterance showed higher perceived naturalness rating than simultaneous head movement with utterance. It is evidence of how important the timing of head movements is and how to enhance HRI through timing adjustment of movements.

4.2. Practical Implications

To enhance social abilities of robots, nonverbal expressions should be considered. Human gestures are commonly multimodal behaviors. However, we should consider the limitations of embodiment in non-humanoid robots. This study showed that minimal head movements of the simple shaped robot significantly improved human-robot interaction.

Having more human-like movement in humanoid robots is not a fundamental solution to making HRI smoother. In contrast, even minimal and simple movements can make interaction between humans and robots more natural. Our study showed an example of the newly designed robot which has a simple shaped body and minimal head movement mechanism. Because of the simple design, it can be easily implemented in other robots as well. Robots with minimal movements and simple shape can easily integrate into our daily lives. Compared to human-like multimodal gestures of humanoid robots, it is less burdensome and can easily blend into various environments.

Our findings also provided that timing adjustment can benefit natural human-robot conversation. We expected that head movement prior to utterance could reduce the long response delay problem in human-robot conversation. People feel unnatural when they wait for the next repose of robots after talking to them. The results showed that the robot's head movement prior to utterance can reduce long response delay problem. Therefore, timing of head movements is important in HRI and can make HRI more natural. Considering nonverbal expressions and timing of movements is necessary when designing and studying the physical interaction of social robots.

4.3 Limitations and Future work

In this experiment, there was a lack of engagement in conversation. Because participants just had short interactions with the robot according to the script. In human interaction, when we are engaged in conversation, we can glean others' immediate intent and purpose (Goffman, 1982). According to Burgoon et al (2011), some level of engagement is required to create interpersonal communication. In the previous study (Kim et al, 2013), engagement of HRI was measured by how participants emotionally involved and felt strong interaction with robots. Engagement is closely related to relationship and social context (Johnston & Taylor, 2018). In order to clearly investigate the social abilities of the robot, future studies should include social engagement in experiments.

Also, this experiment was conducted in the virtual simulation environment. To investigate the effects of head movements of the robot, video resources of the robot's responses were prepared in advance. Since participants had a conversation with the robot on the screen, their concentration might not be on a level with real human-robot conversation. Future investigation should be conducted in more realistic environments.

Additionally, in this study, we manipulated three types of head movements, nodding (A), shaking (B) and tilting (C), which are widely used and typically understood in human interaction. However, cultural differences also exist in head gestures (Kita, 2009; Mandal, 2014; Hasler et al., 2017). We should consider cultural diversity of gestures in HRI as well. Therefore, it should be necessary to find cross-cultural representative gestures in HRI or to localize robot's gestures according to cultural differences.

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Appendix

Appendix 1: Godspeed Questionnaire (Bartneck et al., 2009b)

가짜같은 (Fake)	1	2	3	4	5	자연스러운 (Natural)
기계적인 (Machinelike)	1	2	3	4	5	인간같은 (Humanlike)
의식이 없는 (Unconscious)	1	2	3	4	5	의식이 있는 (Conscious)
인공적 (Artificial)	1	2	3	4	5	생물적 (Lifelike)
어색한 움직임 (Moving rigidly)	1	2	3	4	5	정교한 움직임 (Moving Elegantly)

죽어있는 (Dead)	1	2	3	4	5	살아있는 (Alive)
활기가 없는 (Stagnant)	1	2	3	4	5	생기있는 (Lively)
기계적인 (Mechanical)	1	2	3	4	5	유기적인 (Organic)
인공적인 (Artificial)	1	2	3	4	5	생물적인 (Lifelike)
상호적이지않은 (Inert)	1	2	3	4	5	상호적인 (Interactive)
무관심한 (Apathetic)	1	2	3	4	5	반응을 하는 (Responsive)

싫음 (Dislike)	1	2	3	4	5	좋음 (Like)
친해지기어려운 (Unfriendly)	1	2	3	4	5	친해지기 쉬운 (Friendly)
불친절한 (Unkind)	1	2	3	4	5	친절한 (Kind)
불쾌한 (Unpleasant)	1	2	3	4	5	유쾌한 (Pleasant)
형편없는 (Awful)	1	2	3	4	5	좋은 (Nice)

무능한 (Incompetent)	1	2	3	4	5	유능한 (Competent)
무지한 (Ignorant)	1	2	3	4	5	박식한 (Knowledgeable)
무책임한 (Irresponsible)	1	2	3	4	5	책임감있는 (Responsible)
무식한 (Unintelligent)	1	2	3	4	5	지적인 (Intelligent)
어리석은 (Foolish)	1	2	3	4	5	현명한 (Sendible)

Abstract in Korean

최근 인공지능 로봇은 일상에서 흔하게 접할 수 있는 것이 되었다. 인간과의 교류가 늘어남에 따라 로봇의 사회적 능력은 더 중요해지고 있다. 인간과 로봇의 사회적 상호작용은 비언어적 커뮤니케이션을 통해 강화될 수 있다. 그러나 로봇은 비언어적 제스처의 표현에 제약을 갖는다. 또한 로봇의 응답 지연 문제는 인간이 불편한 침묵의 순간을 경험하게 한다. 본 연구를 통해 로봇의 고개 움직임이 인간과 로봇의 상호작용에 어떤 영향을 미치는지 알아보았다. 로봇의 고개 움직임을 탐구하기 위해 단순한 형상과 고개를 움직이는 구조를 가진 로봇을 새롭게 디자인하였다. 이 로봇을 활용하여 로봇의 머리 움직임과 타이밍이 참여자에게 어떻게 지각되는지 실험하였다. 참여자들은 3가지 움직임 조건인, 끄덕임 (A), 좌우로 저음 (B), 기울임 (C) 중 한 가지 조건에 무작위로 선정되었다. 각각의 고개 움직임 조건은 두 가지 타이밍(음성보다 앞선 고개 움직임, 음성과 동시에 일어나는 고개 움직임)의 변수를 갖는다. 모든 타입의 고개 움직임에서 움직임이 없는 조건과 비교하여 로봇의 인격화, 활동성, 호감도, 감지된 지능이 향상된 것을 관찰하였다. 타이밍은 로봇의 음성보다 고개 움직임이 앞설 때 자연스러움이 높게 지각되는 것으로 관찰되었다. 결과적으로, 로봇의 고개 움직임은 사용자의 지각에 긍정적인 영향을 주며, 앞선 타이밍의 고개 움직임이 자연스러움을 향상시키는 것을 확인하였다. 고개를 움직이는 동작과 타이밍을 통해 단순한 형상의 로봇과 인간의 상호작용이 향상될 수 있음을 본 연구를 통해 확인하였다.