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The Effect of Interaction with a Dog on Heart Rate Variability based on Lorenz Plot Analysis

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Animal Assisted Intervention (AAI) is widely used in therapeutic and educational situations. It is necessary to describe the effects of AAI based on objective indices to facilitate the effective use of AAI. We investigated the effects of interacting with a dog on sympathetic and parasympathetic nervous system activities by evaluating heart rate variability (HRV) using the Lorenz plot method. Participants were thirty-four healthy volunteers (17 females and 17 males, 20-29 years of age), randomly assigned to one of three groups: the dog group, the stuffed dog group, and the plant group. Participants rated their impressions of the target (the dog, the stuffed dog, or the plant) by touching it between task blocks. The participants completed a mood scale in each block, and we measured their heart rate, respiration rate, and skin conductance response. Results indicated that interactions with the dog increased the cardiac sympathetic index of Lorentz plot, skin conductance responses, and "high-arousal and pleasant mood" score compared to the other conditions. These results suggest that short interactions with a dog activate the sympathetic nervous system, which causes an awakening effect.

Key words: animal-assisted intervention, pet dog, heart rate variability, Lorenz plot

Author Note

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Animal-assisted intervention (AAI) is widely used in therapeutic and educational situations. AAI has been conducted in different ways with ingenuity in each field. AAI has a variety of positive effects on humans, including enhancing motivation (e.g., Wolfarth et al., 2013), stress reduction (e.g., Beetz et al., 2000), and facilitating prosocial behavior (e.g., Eddy et al., 1988). It is necessary to understand the characteristic effects of AAI and apply appropriate methods to increase the efficacy of AAI; however, only a few studies have evaluated the efficacy of AAI using objective indices. Several studies have used physiological indices to evaluate the relaxation and stress reduction effects of AAI. These physiological indices have included the central nervous system activity (e.g., Aoki et al., 2012; Calcaterra et al., 2015), the peripheral (autonomic) nervous system activity (e.g., Friedmann et al., 1983; Vormbrock & Grossberg, 1988; Demello, 1999; Beetz et al., 2011), the endocrine/immunity system activity (e.g., Odendaal & Meintjes, 2003; Charnetski et al., 2004; Miller et al., 2009). Autonomic nervous system activity has been most commonly used because of its low burden on participants.

Generally, many studies report that interactions with dogs reduce the cardiovascular response as measured by heart rate and blood pressure (e.g., Friedmann et al., 1983; Allen et al., 1991; 2001; Nagengast et al., 1997). For example, Negengast et al. (1997) measured cardiovascular responses of children during a physical examination and found that when there was a dog present, blood pressure and heart rate were lower than when there was no dog present. Allen (2002) conducted a calculation task and cold pressor test and found that heart rate and blood pressure were lower, reactivity to a stressor was less, and recovery was quicker when there was a dog present, compared to a friend. Conversely, some experiments have reported no changes in heart rate (Grossberg et al., 1988; Hansen et al., 1999) or even an increase in heart rate from interactions with dogs (Vormbrock & Grossberg, 1998; DeMello et al., 1999). Vormbrock & Grossberg (1998) reported an increase in heart rate through verbal and tactile interactions with dogs, and DeMello (1999) found that heart rate increased during tasks when a dog was present.

Measurements of heart rate have mainly evaluated autonomic nerve activities. However, the autonomic nervous system is composed of the sympathetic and parasympathetic nervous system, and both are involved in adjusting internal organs, including the heart. Therefore, it is necessary to examine the two nerve activities separately. In order to separate the effect of the sympathetic and parasympathetic nervous system (vagus nerve) on heart rate, the heart rate variability (HRV) measure is widely utilized. Heart rate variability is greatly affected by respiration. Heart rate decreases during exhalation and increases during inhalation. This synchronization is associated with an increase in vagal activity. Many methods have been proposed to analyze HRV (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). These methods are classified by the time domain method (e.g., SDNN, pNN50, RMSSD), frequency domain method (e.g., HF, LF, HF/LF), and non-linear method (e.g., Lorenz plot).

The most frequently used method is the frequency domain method, which applies frequency analysis on time-series data of R-R intervals. The high-frequency component (HF; 0.15-0.4 Hz) reflects the parasympathetic (vagus) nerve activities, and the low-frequency component (LF; 0.04-0.15 Hz) reflects both sympathetic and parasympathetic nerve activities. However, the frequency domain method involves a complex calculation process such as interpolation, resampling, and frequency analysis (Fast Fourier Transform in most of the cases). There is also the problem of respiratory control, especially when the respiratory rate is less than 9 times per minute (0.15 Hz or under: LF band). In these cases, the results are difficult to interpret.

Previous studies have examined heart rate variability during interactions with dogs (e.g., Motooka et al., 2006; Gee et al., 2014; Schretzmayer et al., 2017). For example, Motooka et al. (2006) measured heart rate variability during a walk with dogs and found HF increased when there was no dog. However, results indicated HF value was smaller than when in the house with a dog and similar to being in the house without a dog. Kerns et al. (2018) analyzed the heart rate variability of children conducting speech tasks and found that there was no difference in the HF whether or not there was a dog present. Further, Gee et al. (2014) conducted a working memory task with university students while touching a dog. As a result of analyzing HF and the root mean square of successive differences between R-R intervals (RMSSD), which also reflects the parasympathetic nerve activities, no significant difference was found between dog, stuffed animals, and other humans. These studies have focused primarily on parasympathetic nerve activity and less on sympathetic nerve activity.

The current study used the Lorenz plot (also known as the Poincaré plot), which is a non-linear method. The Lorenz plot is plotted on a graph with (n)th R-R interval on the horizontal axis and (n+1)th R-R interval on the vertical axis, and it usually shows an oval distribution. The area of the oval indicates the parasympathetic (vagus) nerve activities (cardiac vagal index: CVI), and the ratio of the oval's minor axis to the major axis indicates the sympathetic nerve activities (cardiac sympathetic index CSI), which makes the calculation process relatively simple (Toichi et al., 1997). Previously, its validity has been confirmed using the autonomic nervous system blocker (Toichi et al., 1997), and it has been compared to other heart rate variability analyses (Guzik et al., 2007).

The purpose of this study is to examine the effect on heart rate variability through interactions with a dog using the Lorenz plot. By using the Lorenz plot, the sympathetic and parasympathetic nerve activities can be examined separately. The participants performed the cognitive task (mental rotation task) before and after the dog interaction, and physiological, psychological, and behavioral indices were measured to evaluate the effects of AAI.

Method

Participants

Thirty-four healthy volunteers participated (20-29 years of age). All participants were right-handed and did not own dogs. They were randomly assigned to one of three groups: dog group (7 females, 6 males, mean age 21.2), stuffed dog group (5 females, 6 males, mean age 23.4), and plant group (5 females, 5 males, mean age 22.4). The purpose of the experiment was explained in writing, informed consent was obtained from each participant, and all participants signed a consent form. They were told that they might interact with dogs, and they did not have allergies to dogs.

Apparatus and Materials

A multi-channel bio-signal amplifier (Polymate AP1132 and AP-U030, Digitex Lab., Tokyo, Japan) was used to measure heart rate (HR), respiration rate, and skin conductance response (SCR). Instantaneous heart rate (R-R interval) was monitored throughout the protocol by a bipolar electrocardiogram (ECG). The ECG was recorded by the standard limb lead III (time constant =0.3 sec.). The respiration wave was recorded with a strain gauge attached to the upper abdomen (time constant =5 sec.). The SCR was derived from Ag/AgCl electrodes (PPS-EDA, TEAC, Tokyo, Japan) attached to the index and middle fingers of left hand (time constant=0.5 sec.). The low-pass filter (30 Hz) and the hum filter were used to reduce artifacts. These signals were analyzed using BIUTASII software (Kissei Comtec, Nagano, Japan). The Lorenz plot analysis was conducted using a program developed by Sato et al. (2002). During the experiment, participants were instructed to remain still as much as possible. Due to a recording defect, data for one participant in HRs, and two participants in SCR were excluded from the analysis.

The mood scale (Two-Dimensional Mood Scale, IMF, Tokyo, Japan) is a questionnaire consisting of eight items, and the participants evaluate their mood using a five-point scale. This scale measures the moods of Vitality and Stability. The Vitality score reflects high arousal and pleasant mood. If the Vitality score is positive, it represents a lively and energetic state, and if it is negative, it represents a sluggish and non-energetic state. The Stability score reflects low arousal pleasant mood. If the Stability score is positive, it represents a relaxed and calm state, and if it is negative, it represents a frustrated and nervous state. The reliability and validity of the scale were confirmed (Sakairi et al., 2003).

Procedure

The experiment consisted of five blocks (Figure 1): first rest block (Rest1), first task block (Task1), rating block (Rating), second task block (Task2), and second rest block (Rest2). The rest and rating blocks were five minutes, and the task blocks were 10 minutes. At the end of each block, the participant was asked to complete the mood scale. Heart rate, respiration rate, and skin conductance responses were continuously recorded.

Figure 1

Procedure in this experiment

Task

The task used in the experiment was the mental rotation task (Cooper & Shepard, 1973). Stimuli were six letters (F, G, J, L, Q, and R). They were presented in normal or reversal positions, and they were tilted at 0, 40, 80, 120, or 160 degrees. Regardless of the angle of tilt, the participants were instructed to press one of two buttons when the position of the presented stimulus was normal and press another button when it was reversed. They were also asked to press the buttons with their index or middle fingers of the right hand as quickly and accurately as possible. Each stimulus was presented within 5 degrees of the participant's visual field (observation distance =60 cm). The inter-trial interval (ITI) was five seconds, and 120 trials were conducted in a block (total 10 minutes). The participants performed 10 practice trials at the beginning of the first trial block to reduce the overall variance of reaction times. Software for behavioral research (E-Prime, Psychological Software Tools, PA, USA) was used to control the presentation of the stimuli and measure responses of the participants.

Rating of impression

In the Rating block, participants were instructed to rate the impression of the target (dog, stuffed dog, or plant) using a semantic differential (SD) scale (Figure 4). The SD scale included some items concerning the sense of touch (i.e., "warm-cold", "smooth-rough", and "hard-soft"), so that all the participants naturally touched the target. The dog group's target was a pet dog (mixed breed, neutered male, 1-year of age, 40cm in height). The dog's owner was an experimenter in the study, and he accompanied his dog during the Rating block. A veterinarian (DACVB) conducted a behavioral evaluation of the dog in advance and confirmed that the dog was suitable for this experiment. The stuffed dog group's target was a stuffed dog (West Highland White Terrier, 40cm in height). The target in the plant group was a house plant (potted pothos, 90cm in height). The dog and stuffed dog were presented on a chair (40cm in height).

Statistical analysis

In this study, an analysis of variance (ANOVA) was conducted. As a result of Mendoza's sphericity test, the sphericity could not be assumed in the analysis, including repeated measurement. The degrees of freedom were corrected by the Huynh-Feldt method. Shaffer's procedure was used for multiple comparisons.

Results

HR and HRV

The mean heart rates (HRs) in each block are shown in Table 1. Heart rate was part of a mixed-design ANOVA with two factors (group and block). There was a significant main effect of the block (F(2.93,87.94)=10.17, p<.001, η^2=.03). Multiple comparisons revealed the mean HR in Task1 was higher than in Rating, Task2, and Rest2, and the mean RT in Rest1 was higher than that in Rest2. The mean HRs decreased as the experiment progressed, and there was no significant difference between groups.

Table 1

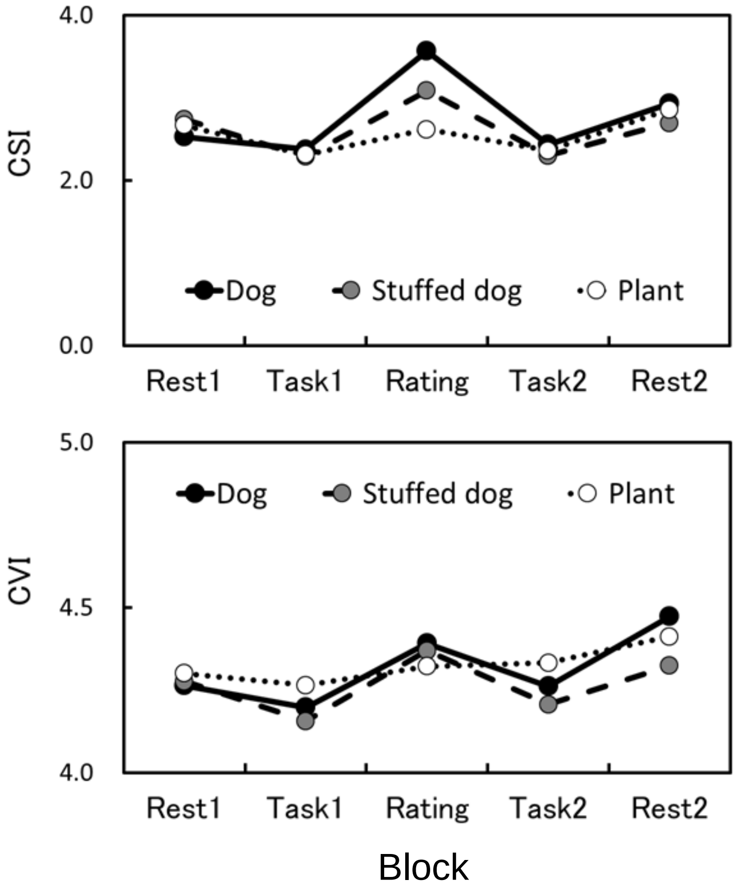
Group	Rest1	Task1	Rating	Task2	Rest2
Dog	82.12	83.09	77.13	79.51	77.44
	(7.14)	(6.83)	(6.67)	(6.35)	(7.49)
Stuffed dog	77.66	79.76	76.54	76.59	74.20
	(11.40)	(12.96)	(10.25)	(11.27)	(9.19)
Plant	76.81	79.38	76.76	75.89	74.74
	(6.73)	(11.25)	(8.82)	(9.74)	(7.88)

Mean HRs (SDs in parentheses)

Heart rate variability (HRV) was analyzed using the Lorenz plot method, and the mean CSIs and CVIs are shown in Figure 2. The mean CSIs were included in a mixed-design ANOVA with two factors (group and block), and there was a significant main effect of the block (F(3.45, 103.56)=12.00, p<.001, η^2=.10) and the interaction of both factors (F(6.9, 103.56)=2.17, p<.05, η^2=.04). Multiple comparisons revealed that the CSI in Rating was higher than those in Task1, Task2, and Rest1 in the dog group (p<.05). In the stuffed dog group, the mean CSI in Rating was higher than in Task1, Task2, and Rest2 (p<.05). The mean CVIs were subjected to a two-way ANOVA, and there was a significant main effect of the block (F(3.44, 103.12)=4.92, p<.01, η^2=.06). Multiple comparisons revealed that the mean CVI in Rating was higher than in Task1, and the mean CVI in Rest2 was higher than in Task1 and Task2 (p<.05).

Figure 2

Mean CSIs and CVIs calculated using Lorenz plot method



SCR and respiration rate

The mean SCRs and respiration rates are shown in Table 2. The mean SCRs were subjected to a two-way ANOVA, and there was a significant main effect of the block ($F(3.99, 111.61)=6.75$, $p<.001$, $\eta^2=.08$) and the interaction of both factors ($F(7.97, 111.61)=1.79$, $p<.10$, $\eta^2=.04$) was significant. Post-hoc tests revealed that the mean SCR in Rating was higher than that in Rest1 in the dog group, and the mean SCR in Rating was higher than those in Rest1, Task2, and Rest2 in the stuffed dog group ($p<.05$).

The mean respiration rates were subjected to a two-way ANOVA, and there was a significant main effect of the block ($F(3.46, 103.87)=21.70$, $p<.001$, $\eta^2=.12$). Multiple comparisons revealed that the mean respiration rates in Task1 and Task2 were higher than those in Rest1 and Rest2, and the mean respiration rate in Task1 was higher than that in Task2 ($p<.05$).

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Table 2

Mean SCRs and respiration rates (SDs in parentheses)

Group	Rest1	Task1	Rating	Task2	Rest2
Dog	82.12	83.09	77.13	79.51	77.44
	(7.14)	(6.83)	(6.67)	(6.35)	(7.49)
Stuffed dog	77.66	79.76	76.54	76.59	74.20
	(11.40)	(12.96)	(10.25)	(11.27)	(9.19)
Plant	76.81	79.38	76.76	75.89	74.74
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	(11.40)	(12.96)	(10.25)	(11.27)	(9.19)
Plant	76.81	79.38	76.76	75.89	74.74
	(6.73)	(11.25)	(8.82)	(9.74)	(7.88)

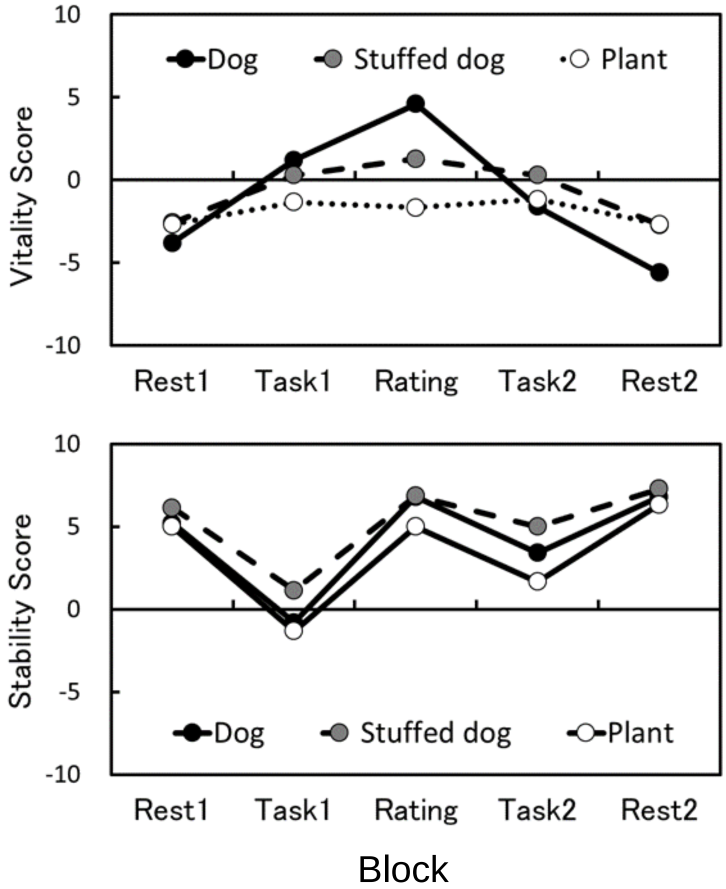
Mood scale

The mean Vitality and Stability scores of the mood scale are shown in Figure 3. The Vitality scores were subjected to a mixed-design ANOVA with two factors (group and block), and there were a significant main effect of the block ($F(3.2, 47.98)=10.62$, $p<.001$, $\eta^2=.26$) and the interaction of both factors ($F(6.4, 47.98)=2.51$, $p<.05$, $\eta^2=.12$). Post-hoc tests revealed that the mean Vitality score of the Rating block in the dog group was higher than those in the stuffed dog and plant groups, and the Vitality score of the Rating block in the stuffed dog group was higher than that in the plant group ($p<.05$). In the dog group, the Vitality score of the Rating block was higher than that of the Rest2 block ($p<.05$).

The Stability scores were subjected to a two-way ANOVA, and there was a significant main effect of the block ($F(3.25, 48.69)=18.89$, $p<.001$, $\eta^2=.41$). Multiple comparisons revealed that the mean Stability score of Task1 was smaller than those of the other blocks, and the Stability score of the Taks2 was smaller than that of the Rest2 ($p<.05$).

Figure 3

Mean scores of the mood scale



Task performance

The mean reaction times (RTs) and the mean correct response rates (%) are shown in Table 3. RTs for correct responses between 250 and 2000 ms were analyzed. The mean RTs were subjected to a two-way ANOVA, and a significant main effect of the block was found ($F(1, 31)=44.77$, $p<.001$, $\eta^2=.10$). Multiple comparisons revealed that the RTs for Task2 was faster than that for Task1. ($p<.05$). The correct response rates were included in a two-way ANOVA, and a significant main effect of the block was found ($F(1, 31)=26.12$, $p<.001$, $\eta^2=.09$). Multiple comparisons revealed that the correct response rate for Task2 was higher than that for Task1. ($p<.05$). There were no significant differences between groups.

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Table 3

Mean RTs and mean correct response rates (SDs in parentheses)

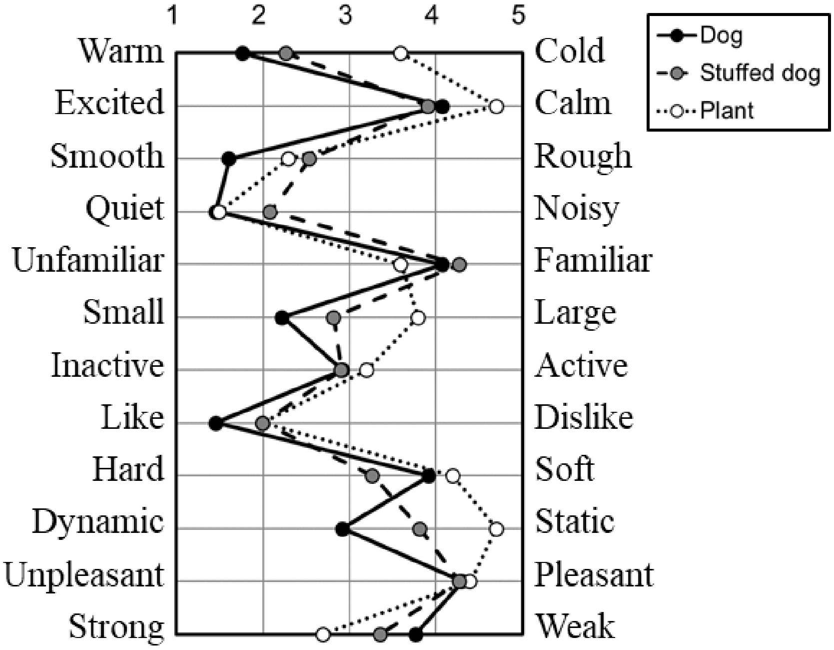
	RT (ms)				Correct response rate (%)			
Group	Task1		Task2		Task1		Task2	
Dog	877.29	(117.50)	815.39	(106.17)	91.47	(6.15)	95.51	(4.28)
Stuffed dog	929.52	(136.31)	827.07	(141.92)	94.83	(5.10)	97.08	(4.80)
Plant	1003.88	(169.54)	888.76	(133.82)	93.94	(4.41)	96.89	(3.21)

Impression rating

The mean rating scores of impressions are shown in Figure 4. The rating scores for each item were subjected to a one-way ANOVA. There was a significant main effect of the group in four items (warm-cold: F(2, 31)=11.29, p<.001, η^2=.42; small-large: F(2, 31)=8.49, p<.01, η^2=.35;dynamic-static: F(2, 31)=7.59, p<.01, η^2=.33; strong-weak: F(2, 31)=4.03, p<.05, η^2=.21). Multiple comparisons revealed that the dog was rated "warmer", "smaller", "more dynamic", and "weaker" than the plant (p<.05). The stuffed dog was rated "warmer" and "smaller" than the plant (p<.05). There was no significant difference between the dog and the stuffed dog.

Figure 4

Mean impression rating scores



Discussion

The purpose of this study is to examine the effects of interactions with a dog using physiological, psychological, and behavioral indices. Results indicate that the CSI of the Lorenz plot increased more during the Rating block than Task blocks in the dog group. The increase in SCR during the Rating block indicates that the sympathetic nervous system was activated by interaction with the dog. However, the parasympathetic nervous system in the Rating block also increased compared to the Task block, suggesting that sympathetic and parasympathetic nervous systems might have been activated. Furthermore, the Vitality measure of the mood score during the Rating block in the dog group was higher than that of other groups, indicating that an interaction with a dog may have an awakening and refreshing effect on participants. Conversely, increases in CSI and SCR have also been observed in the stuffed dog group, which suggested that a smaller, but similar effect also occurred with the stuffed dog.

Many previous studies reported the activation of the parasympathetic nervous system during interactions with dogs. However, there are also a few studies demonstrating the sympathetic nervous system's activation. In the study by DeMello (1999), interactions with dogs increased the cardiovascular response. During the task, the presence of dogs became an obstructing stimulus and possibly increased the participants' awareness. However, the participants in the current study rated the impression of the dog during the Rating block, and the dog did not appear to be an obstructing stimulus. Additionally, the impression rating results showed that the participants did not have negative impressions of the dog. Vormbrock & Grossberg (1998) reported that verbal and tactile interactions with dogs increased heart rate, which is considered to be due to talking and body movements of the participants. In this study, the frequency of touching the targets (dog, stuffed dog, plant) was the same in all groups, and it is unlikely that there were more body movements in the dog group compared to the other groups.

In studies that examine the relationship between heart rate variability and positive emotions, there is evidence of activation of the sympathetic nervous system. Duarte & Pinto-Gouveia (2017) examined heart rate variability during the arousal of positive emotions (feeling active, relaxed, safeness/contentment). Accordingly, there was a non-linear relationship between HF and safeness/contentment. When the HF was extremely high or extremely low, the safeness/contentment values were low. Kop et al. (2011) investigated heart rate variability when remembering past happy events. Result demonstrated an increase in LF and LF/HF and activation of the sympathetic nervous systems. In addition, Shiota et al. (2011) tested positive emotions' effects on the autonomic nervous system and found that the sympathetic nervous systems were activated during high arousal positive emotions. Therefore, it seems reasonable to consider that the sympathetic nervous system's activation may also have been caused by the high arousal positive emotion that occurred during interactions with the dog.

A fact that should be considered in the interpretation of results is how the dog was introduced. In this study, the participants interacted with the dog during the impression rating, and the dog did not enter the experiment rooms during tasks. This is because if a dog entered the room during tasks, it could be a distraction and might have an obstructive effect on task performance. This study did not introduce dogs during tasks and confirmed the sympathetic and parasympathetic nervous system's activations, but it is unclear if the same effects can be obtained if dogs were introduced during tasks. Also, as already mentioned, the previous studies reported that interactions with dogs activated the parasympathetic nervous system (e.g., Friedmann et al., 1983; Allen et al., 1991; 2001; Nagengast et al., 1997). The interactions with the dog in this study were limited to a short period of time at 5 minutes, but if the interaction time were longer, there is a possibility that the sympathetic nervous system would be deactivated. In this case, only the activation of the parasympathetic nervous system was observed. Further examinations are needed to examine how and when the dogs should be introduced.

With regards to the performances during the tasks, the responses in Task2 block were faster and more accurate than Task1 block in all groups. All groups had improvements in task performances, with no difference based on the participants' interactional partner. This could be because the task difficulty was too low. Therefore, minimal differences were found between the groups. A practice session was conducted before the actual experiment. All participants in the experiment were thoroughly familiar with the tasks, and the average response accuracy in the actual experiment exceeded 90% on average. As a result, it could be that there was a ceiling effect that prevented the difference between each condition from occurring.

There are several limitations to this study. First, there is an issue with sampling bias. Applicants to the study were informed of possible contact with dogs during the experiment to avoid participants with allergies or phobias of dogs. Therefore, many of the participants may have participated because they wanted opportunity to interact with dogs. The similar results between the dog and stuffed dog groups may also be due to the sampling bias. However, the participants were limited to people who do not own dogs at home, so extreme sampling bias could be avoided, and similar effects could be obtained in any participants who spontaneously touch dogs. Second, only one dog was used in this experiment. The effects of the dog breed and behavioral traits of the dog need to be examined in future research.

This study's results indicate that the effects of AAI may differ depending on how the dog is introduced. It is essential to consider the appropriate conditions of introducing the dog depending on the purpose of providing AAI, which will increase the benefits to the participants.

It was hypothesized that the sympathetic nervous system would be activated after interactions with a dog. However, results were based on short time interactions. It is possible that different ways of introducing dogs in the session may change the results. In the future, it is necessary to clarify when and how to introduce dogs in order to make AAI more effective.

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