



Animacy Perception Based on One-Dimensional Movement of a Single Dot

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Abstract. How humans perceive animacy based on movement is not well understood. In the present study, we conducted an experiment to investigate how humans perceive animacy based on the one-dimensional movement of a single dot. Ten participants were asked to generate 60 s of one-dimensional movement with three assumptions: randomness, inanimacy and animacy. The time-series analysis revealed that the movements generated with the assumption of randomness were similar to white noise, the movements generated with the assumption of inanimacy were periodic, and the power spectra of the movements generated with the assumption of animacy were located between pink and brown noise with trajectories with autocorrelations but no clear periodicity.

Keywords: Animacy perception · Movement of a single dot
Time series analysis

1 Introduction

Humans can distinguish between animate and inanimate motion. Many studies have revealed which characteristics contribute to the perception of animacy. According to previous studies, self-propelled motion, in which a stationary object starts to move without an external force [1–3], movement that violates a physical law [4], goal-directed movement [5], contingent movement [6], the environment and context [4], temporal features and the complexity of interactions [7], and intra-system movement of 2-link mechanisms [8] are reported as types or features of movement that result in a perception of animacy.

Humans do not perceive animacy in unpredictable physical behaviors, such as leaves falling, or in easily predictable mechanical behaviors [9]. We hypothesize that one of the factor for animacy perception is a balance of predictability and unpredictability.

Tremoulet and Feldman [10] showed the motion of a single object to participants on a computer screen and asked them to rate its animacy. The results showed that subjects' animacy ratings were significantly influenced by the magnitude of the change in speed and the angular magnitude of the change in direction, which indicates that both predictability, as perceived based on uniform

linear motion, and unpredictability, as perceived based on the sudden changes in speed and angle, contributed to the perception of animacy.

Fukai and Terada [11] conducted an experiment with human participants to clarify the difference between animacy and intentionality in terms of the predictability of behavior. They modeled the behavior of goldfish using an autoregressive model and created movies of a white dot moving on a black background by changing the magnitude of the change in velocity and the rotation angle. The movies were presented to participants, who were asked to chase the white dot with a pen on a tablet to quantify the predictability of its behavior. The participants were also asked to rate the moving dot's animacy and intentionality. The results showed that the subjective impression of animacy increased, and the subjective impression of intentionality decreased as predicting the dot's behavior became more difficult.

Fukai et al. [12] revealed the cause of animacy perception through psychological experiments based on the motion of a simulated double pendulum. The double-pendulum equations lead to a variety of motions, from simple swinging to chaos, depending on their parameters. The participants were instructed to adjust the parameters to the values for which they perceived the most and least animacy. The results indicated that humans do not perceive animacy in periodic motions with little randomness. Furthermore, they reported that the human perception of animacy was comparatively small for most random motions. In contrast, humans perceived animacy strongly in non-stationary random motion with temporal structures, such as motion in which small circular movements occur irregularly.

As mentioned above, although studies suggest that motions with both predictability and unpredictability contribute to the perception of animacy, the property and the extent to which predictability and unpredictability contribute to this perception is not clear. Therefore, in the present study, we use a simple environment in which motion of a single dot is constrained to one dimension to facilitate a time series analysis. In addition, we use a method in which participants generate motion themselves to explore the various motion features that contribute to animacy perception.

2 Method

2.1 Participants

Ten healthy graduate and undergraduate students (10 male, $M_{age} = 23.2$ years, $SD_{age} = 1.4$ years, age range: 21–25 years) participated in the experiment.

2.2 Apparatus

Figure 1 shows the apparatus used in our experiment. A wireless mouse was fixed on a block that slid freely along a rail with a length of 270 mm. The apparatus limited the motion of the participants' hands to the lateral direction.



Fig. 1. Apparatus



Fig. 2. Graphical user interface

The interface used in this experiment is shown in Fig. 2. On the screen, a white dot and the remaining time were shown. The position of the white dot was controlled by the mouse. Therefore, the white dot moved horizontally across the screen following the mouse's movement.

2.3 Procedure

The participants were asked to read a document in which the purpose of the experiment and the method for controlling the apparatus were written. When the experiment started, the screen, as shown in Fig. 2, was shown to the participants. The participants were asked to move the dot on the screen. A one-minute training period was given to the participants. Then, they were asked to move the dot in such a way that they felt the three characteristics were exhibited in the motions they generated. The three characteristics were randomness, inanimacy, and animacy. Participants were asked to move the dot for one minute for each motion category.

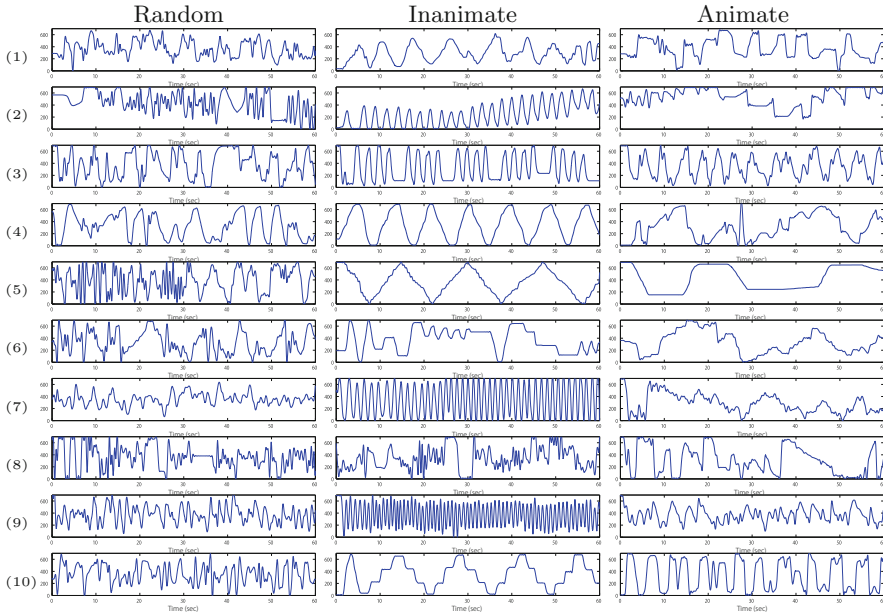


Fig. 3. The trajectories of the x-coordinate of the white dot generated by the ten participants. The left column identifies the participants by number.

2.4 Measurement

The trajectory of the mouse was recorded, and an autocorrelation analysis was performed. The following questionnaire was given to the participants after they finished to movement generation session.

- What type of movement did you imagine when you created the random movement?
- What type of movement did you imagine when you created the inanimate movement?
- What type of movement did you imagine when you created the animate movement?

3 Results

3.1 Trajectory

The trajectories of the x-coordinate of the white dot generated by all ten participants are shown as a function of time in Fig. 3.

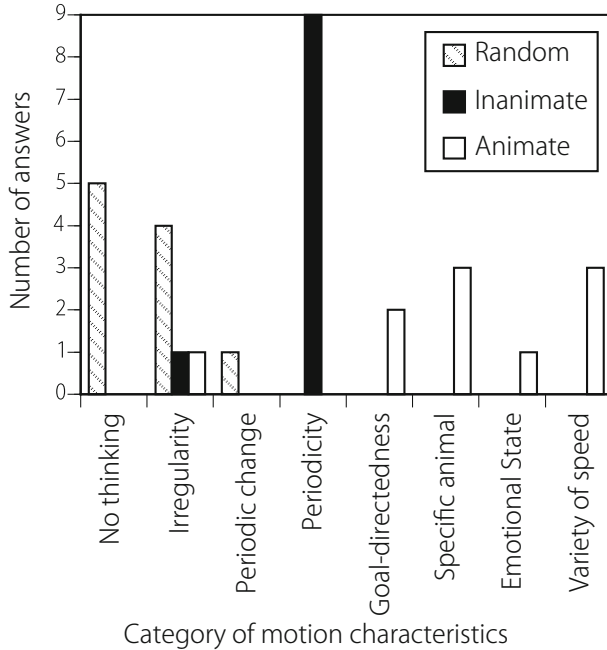


Fig. 4. The motion characteristics assumed by participants.

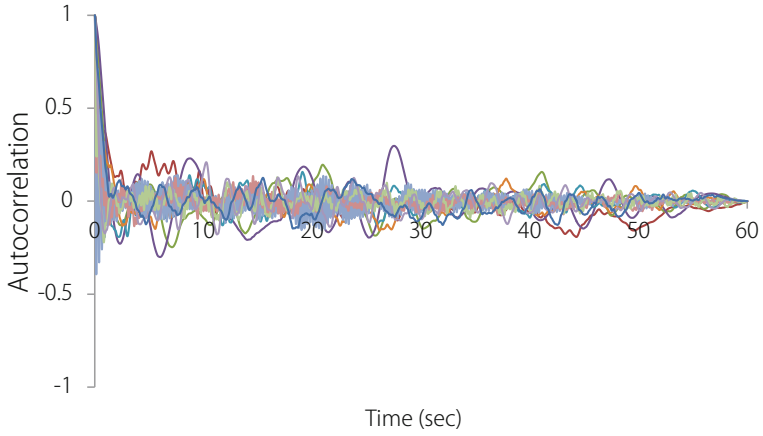
3.2 Questionnaire

Figure 4 shows a histogram of the answers to the post questionnaire. We defined eight motion characteristics that were imagined by participants when they moved the mouse. Most of the participants assumed nothing and irregularity when they generated the random movement. Most of the participants assumed periodicity when they generated the inanimate movement. Most of the participants assumed goal-directedness, a specific animal, such as a fly or a spider, an emotional state, and a variety of speeds when they generated animate movement.

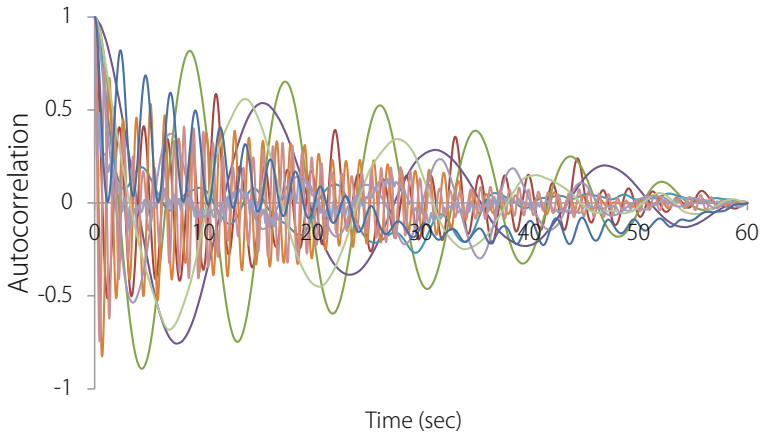
3.3 Time Series Analysis

A time series analysis was performed on the trajectories generated by the participants to investigate the temporal features of the trajectories. First, we calculated the autocorrelation function of the trajectory of the dot to determine the extent to which its motion was periodic.

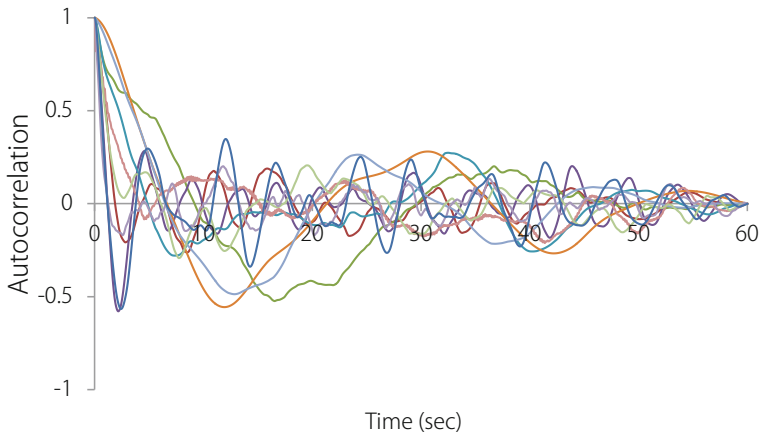
Figure 5a, b, and c show the autocorrelation functions for the random, inanimate, and animate motions of the dot, respectively. Note that the data for all ten participants are shown on one graph. The figures show that the autocorrelation is weak in the random condition, both autocorrelation and periodicity are observed in the inanimate condition, and although periodicity is not observed, some trajectories exhibit autocorrelation.



(a) Random



(b) Inanimate



(c) Animate

Fig. 5. Autocorrelation functions of the movements generated by the participants.

Table 1. Means and standard deviations of the autocorrelations.

Condition	Mean	SD
Random	.06	.02
Inanimate	.16	.07
Animate	.13	.08

Table 1 shows the mean and standard deviation of the mean absolute values of the autocorrelation calculated for 60 s for each participant. A one-way ANOVA ($F(2, 27) = 8.70, p < .01$) confirmed a significant difference in the mean absolute value of the autocorrelation. Fisher's LSD post-hoc test revealed that the mean absolute values of the autocorrelation were significantly higher in the inanimate and animate conditions than in the random condition ($p < .01$).

The peaks with correlations of at least 0.3 in the autocorrelation function were counted. The mean numbers of peaks were 0.1, 4.7, and 0.1 in the random, inanimate, and animate conditions, respectively.

We calculated the inclination of the regression lines of the power spectral density functions graphed on a double-logarithmic scale up to 1 Hz. The mean inclinations were -0.86 , -1.33 , and -1.63 for the random, inanimate, and animate conditions, respectively. A one-way ANOVA ($F(2, 27) = 2.73, p = .08$) confirmed a marginally significant difference in the mean inclination of the regression lines. Fisher's LSD post-hoc test revealed that the mean inclination was greater in the random condition than in the inanimate condition ($p < .05$).

4 Discussion

In the present study, we asked participants to generate three types of one-dimensional movement that they felt exhibited randomness, inanimacy, and animacy. In this section, we discuss the features of each movement.

For the movements to which participants assigned randomness, subjective reports obtained from the post questionnaire revealed that most of the participants assumed nothing and irregularity. In consistent with the subjective reports, the autocorrelation was low, and the movements were similar to white noise. These results indicate that participants could actually generate random movement.

For the movements to which participants assigned inanimacy, subjective reports revealed that almost all the participants assumed periodicity when they generated the movements. The autocorrelation analysis provided consistent results in which the movements were periodic.

The procedures of the experiment are considered one of the reasons why participants assumed periodicity as a feature of inanimate movement. The opposite of animacy is not necessary periodicity. Random movement is sometimes assumed to be the opposite of animate movement. However, the participants in our study

were first asked to generate random movement. Therefore, they excluded randomness when they generated inanimate movement but assumed periodicity.

For the movements to which the participants assigned animacy, subjective reports revealed that the characteristics assumed when they generated the movements were more widely distributed than they were for the other two conditions. This means that people attribute many characteristics to animate movement. However, the following can be said based on the results of the time series analysis. The proportion of high frequency components included in the movement generated when participants imagined animacy was less than it was for the other types of movement. Colored noise, such as $1/f$ noise (pink noise) and $1/f^2$ noise (brown noise), are identified by the change in the power spectral densities of their time series, which is inversely proportional to the frequency of the change. It is known that pink noise is seen in biological phenomena, such as heart rate variability and firefly luminescence patterns. It is also known that pink noise induces predatory behavior in fish [13].

With colored noise, stronger autocorrelations are observed when the attenuation rate of the power spectral density increases. According to the approximation using data up to 1 Hz in our experiments, we found that the frequency spectrum of the motion generated in the animacy condition was between those of pink and brown noise. Furthermore, the exponent of the power approximation was greater in the animacy condition than in the other conditions. Given that the periodicity of the movement which participants imagined expressed inanimacy was strong, the movement produced with imagined animacy exhibited a temporal correlation and was neither random nor periodic. This finding is consistent with the reports of Fukai and Terada [11] and Fukai et al. [12].

Three of the participants noted that they had varied the speed of the movement in the animacy condition. In addition, the two participants who tried to express goal-directedness in the animacy condition did not actually generate linear movement, which is the most goal-directed, but rather, generated fluctuating motion. The trade-offs between exploration and exploitation in a reinforcement learning agent can be considered a mechanism to generate such movements. If the exploration rate is high, past experiences can not be used, and there is a high possibility of missing an unexploited profit that has already been found. The higher the exploitation rate is, the more likely an agent is to miss the new higher profit. Therefore, an appropriate balance of exploitation and exploration is important for agents. Exploration is the cause of random movements, and exploitation is cause of linear and goal-directed movements. There is a possibility that such properties of agents may affect the perception of animacy by their combination of randomness and regularity.

5 Conclusion

We hypothesized that one of the factors for animacy perception is a balance between the predictability and unpredictability that are observed in the behavior of a target. In the present study, we analyzed the time series of the motion of a

single dot constrained to one dimension generated by participants to identify the properties and predictability or unpredictability that are related to a perception of animacy. The results showed that periodic changes that have clear temporal structures and white noise without autocorrelation are not perceived as animate movements. We also found that humans perceive animacy from temporal change with a frequency spectrum between those of pink and brown noise. Although, in the present study, we assumed a stationarity when we analyzed the movement, the movements of living organisms are essentially non-stationary and reflect internal state changes. We will examine the characteristics of movement that contribute to animacy perception in detail in the future by assuming internal state transitions.

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