ORIGINAL ARTICLES

SPEED TUNING OF BIOLOGICAL MOTION PERCEPTION

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Abstract: In order for humans to communicate, it is important to predict the feelings, thoughts, and intentions of other people not just through verbal information but also through movement information. Therefore we must identify what an action of a person is in. Although it appears to be a highly complicated and difficult task, humans can recognize complex movements of an individual even with impoverished motion information. We examined how presentation rates (speeds) affect the detection of biological motion. In a two-alternative forced-choice task, subjects discriminated normal biological motion sequences from scrambled versions. Upright and inverted stimuli were presented in a forward or backward order at various presentation rates. Performance was generally higher in the condition where the stimuli were presented upright in a forward manner than the other conditions. A clear tuning curve for presentation rate was observed only in the upright-forward condition. These results suggest that the perception of natural biological motion takes into account previous experience in observing human actions.

Keywords: *Biological motion, Speed tuning, Visual, Experience*

1. INTRODUCTION

The human perception of biological movements is flexible and remarkably robust in a variety of natural situations. This was first demonstrated by Johansson's classic study [1]; his point-light animation involved small light marks placed on the major joints of an individual engaging in various activities. Individuals can readily recognize human movement even from the movement of just several dots. This is known as "biological motion perception," and there exist a vast number of studies as well as good reviews [2-4].

Numerous experiments have demonstrated the robustness of this visual ability. Perception of biological motion is possible even in conditions in which the dynamic noise masked motion sequences [5-7] or the contrast polarity of the dots of biological motions were varied across frames [8]. Moreover, substantial recognition performance was acquired even when just a few of the moving dots were visible, when the duration of the individual dots was limited, and when the dots were displaced on the invisible skeleton in every frame [9-12].

In addition, individuals are also able to extract detailed information from biological motion sequences. By viewing point-light animations, the gender of an actor can be reliably discriminated [13-21], a familiar individual can be identified [14][22-24], and so can the emotions of an actor [25][26]. With regard to these phenom-

ena, it is thought that biological motion perception is shaped by previous experience. Partially supporting this statement, biological motions that we have learned are easier to recognize than biological motions that we view for the first time [27]. Further, the quick and efficient processing of biological motion can be supported by depicted actions that are familiar biological motions [28]. These studies support the hypothesis that the perception of biological motion involves top-down processes that are formed by experience.

In the present study, we examined another parameter that may be influenced by experience, namely, the presentation speed of biological motion. An earlier study in which motion animations of animals and humans were presented at three different presentation rates suggested that with upright stimuli, subjects perceived the recovered coherent structure, but with inverted stimuli, subjects were unable to perceive the invariant structure for all types of motion [29]. In order to clarify the effect of presentation rate on biological motion perception, we derived speed tuning curves for biological motion perception.

Subjects performed a discrimination task between normal biological motion and scrambled biological motion. The presentation rate of biological motion was manipulated. Stimuli were presented in either upright or inverted form and in either forward or backward manner.

The derived speed tuning of biological motion perception could provide evidence for the experience-dependent processes for biological motion processing and would also be informative with regard to the artificial implementation of flexible and robust (human-like) analyses of motor behaviors (e.g., gesture recognition by machine vision).

2. EXPERIMENT 1

2.1. Methods

2.1.1. Subjects The subjects comprised 5 adults (2 females, 3 males), including the authors of this paper (HI, KW). All the subjects had normal or corrected-to-normal vision. Apart from the authors, all the other subjects were naïve regarding the purposes of the study.

2.1.2. Stimuli and apparatus We used point-light biological motion sequences as the stimuli. These stimuli were created from videotapes of a moving individual wearing dark clothing with reflective tape on the 12 major joints (Figure 1a). The individual in

Figure 1: Visual stimuli. (a) Upright biological motion stimuli comprised 12 black dots on a white background. The lines connecting the dots were not shown in the actual experiment. (b) Biological motion stimuli were shown embedded in noise dots involving the same motion trajectories as the signal dots component of the motion being masked [5]. (c) Scrambled biological motion stimuli were created by randomizing the starting positions of the signal dots of the biological motion in the same trial.

the videotape performed five activities (jumping, running, walking, kicking, and throwing a ball). On a white (58 cd/m^2) background, the movements of 12 black (0.4 cd/m^2) dots depicted the biological motions. The height and width of the biological motion stimuli were set to 4 deg and 2 deg, respectively. Each biological motion could also be presented in the form of mirror-reversed images; thus, a total of 10 types of biological motion stimuli were used. The visual stimuli were presented on a 21-inch CRT display (refresh rate 100 Hz), which was

controlled by an Apple Macintosh G4 computer.

Biological motion animations were masked by the motion of noise dots [5][6], which had the same size and dynamics of the dots produced by the biological motion sequences (Figure 1b). This procedure made it difficult to perceive biological motions. In a trial, the noise dots moved as well as the dots of biological motion; the motion trajectory of each noise dot was chosen from one of the 12 dots of the to-be-masked biological motion sequence. The starting position of each noise dot was randomly determined within a virtual square area (5.6 deg on each side) centered on the masked biological motion dots.

The presentation rate of the animations was varied (100, 50, 25, 12.5, and 6.25 Hz) and the 25 Hz presentation rate corresponded to the normal (i.e., video-taped) speed. All biological motion animations consisted of 20 frames. Consequently, the interval of the biological motion stimuli varied with the presentation rate, which was fixed within a session.

In addition to the upright biological motion sequences, we also measured the speed tuning curves for the inverted biological motion in order to examine whether inverted biological motions lead to a speed tuning similar to that of the upright biological motions. The trajectories of the noise dots for the inverted biological motion were selected from the dots in the inverted biological motion condition.

2.1.3. Procedure The subjects were seated in a lit room and viewed the screen from a distance of 57 cm with their heads fixed with a chin rest. They were asked to fixate on a cross stimulus (0.43 deg) at the center of the display during each trial. A key press initiated the presentation of two successive stimulus sequences separated by a blank period of 500 ms. One of the two intervals, which was randomly determined for each trial, presented one of the five biological motion sequences, while the other interval presented the scrambled version of the stimulus. The scrambled version was created by randomizing the starting positions of the dots that defined the biological motion sequence in the same trial (Figure 1c). The biological motion sequence always started at the same frame. After the completion of two intervals, the subjects pressed one of the two keys to report which interval contained the normal, unscrambled biological motion sequence. If necessary, the subjects engaged in guessing their response. The response time was not con-

sidered and auditory feedback was provided immediately after each response. Upright and inverted biological motions were examined in separate sessions.

We used a staircase procedure to vary the number of noise dots to a level associated with 84% of correct performance on this two-alternative forced-choice (2AFC) task [5]. A three-up/one-down staircase rule was used: three consecutive correct responses added 4 noise dots to the noise level of the current trial, and a single incorrect response reduced the noise level by 4 dots. After 12 reversal points of the staircase, both increased and decreased noise levels were reduced to 2 dots. When the number of reversal points reached 18, the staircase was considered as completed. Further, "performance" was defined as the average of the noise levels of the last 5 reversal points. Trials were self-paced, and subjects were allowed to rest whenever they wished.

2.2. Results and discussion

The results of Experiment 1 are depicted in Figure 2, in which the average noise levels required to yield a criterion level of performance are plotted. Higher values of noise indicate superior detectability of the biological motion. The data are plotted as functions of presentation rates of the stimuli, with orientation as the parameter. The detection performance was higher for upright stimuli than that for inverted stimuli (inversion effect; [30-34]). A two-way analysis of variance (ANOVA) with repeated measures revealed the main effects of stimulus type (upright vs. inverted, $F(1,4) = 56.13$, $p < 0.05$) and presentation rate ($F(4,16) = 14.84$, $p < 0.05$). The interaction between stimulus type and presentation rate was also significant ($F(4, 16) = 3.62$, $p < 0.05$). Post-hoc Tukey HSD tests indicated that in the upright condition, the detection performance was the highest when the animation speed was 25 Hz (normal speed) ($p < 0.05$). Thus, when the upright stimuli were presented, there was a speed tuning curve with the clear peak performance at 25 Hz. However, when inverted stimuli were presented the performances at all presentation rates were not significantly different. Thus, familiar biological motions such as upright stimuli were best detected at the speed at which people usually view the action. This result suggests that biological motion perception may be dependent on experience.

Figure 2: Results of Experiment 1. Averaged detection performances are plotted as a function of presentation rate. Vertical bars = 1 SE.

3. EXPERIMENT 2

Our increasing daily experience with video clips reveals that some natural events, including different types of locomotion, appear unrealistic when shown backwards. This is also true for the biological motion perception [35], although biological motion sequences that are presented in a backward manner have the same kinematics as those presented in a forward manner.

In Experiment 1, the presentation rate had little influence on the detection performance of the inverted stimuli. In other words, a natural presentation rate (speed) does not facilitate biological motion perception when the stimulus is inverted. This is presumably because the subjects have little experience in observing inverted human actions. Likewise, a backward presentation may impair biological motion perception and hinder the speed tuning observed in the forward upright condition.

3.1. Methods

The subjects, stimuli, and procedure were identical to those used in Experiment 1. The only exception was that in this experiment we used reversed sequences of animations, which were created by reversing the presentation order of the stimuli frames used in Experiment 1.

3.2. Results and discussion

Figure 3 shows the results of Experiment 2. No clear peak of speed tuning was observed. Instead, for both the upright and inverted conditions, the curves were very

similar to that in the inverted condition of Experiment 1. An ANOVA revealed main effects of stimulus type (upright vs. inverted, $F(1, 4) = 12.24, p < 0.05$) and presentation rate ($F(4, 16) = 5.44, p < 0.05$). However, unlike Experiment 1, the interaction was not significant ($F(4, 16) = 0.22, p > 0.05$). This lack of interaction indicates that speed tuning for upright biological motion (which was clear in the forward condition) was absent when the stimulus was presented in a backward manner. In both the upright and inverted conditions, Tukey HSD tests indicated that there was no significant difference among the different presentation rates, with the exception of the difference between 25 Hz and 6.25 Hz ($p < 0.05$), which is likely to be accidental. Thus, when the presentation order was reversed for biological motion, the visual system may not depend much on experience-dependent cues that are tuned to normal presentation speed.

Figure 3: Results of Experiment 2.

4. GENERAL DISCUSSION

The present study revealed that biological motion perception is best when the stimulus is presented in "natural" conditions, thereby confirming the experience dependency of biological motion perception [27-28][36]. However, the speed tuning to the natural presentation rate was evident only when the upright stimuli were presented in the forward manner. These results suggest that the robustness and efficiency of biological motion perception may be critically dependent on the dynamics of human movements, which include constraints in the

physical world such as gravity and time's arrow.

However, it should be noted that the detection of human movement is still possible based on clues other than the specific dynamics and constraints of human movements. Although the detection performance is comparatively low with inverted stimuli and backward presentation, the subjects were able to detect the biological motion in the presence of considerable noise. Yet, the absence of clear speed tuning in these "unnatural" conditions suggests that the processing involved in the detection of unnatural human movements may not be based on domain-specific experience but utilizes more generalized mechanisms that are immune to changes in movement dynamics (e.g., structure-from-motion [37], configural form processing [38]). The lack of an inversion effect in the backward conditions can be understood if the visual system uses a generalized mechanism, which ignores experience-based top-down processes, in the recognition of unnatural human movements.

People can recognize gender by observing gait and facial/head motion [13-21], estimate dynamics such as the weight of a lifted object [39-42], identify individuals by observing their gait patterns and arm movements [22-24], and infer emotions by observing dance and arm movements [25][26][43][44]. It would be interesting to investigate whether these faculties associated with biological motion depend on presentation rate and forward-backward presentation of the stimuli. Our current conjecture is that a biomechanical invariant is the key for enabling the rapid extraction of information involved in human movement patterns associated with learning through experience. However, in order to directly demonstrate that the perception of natural biological motion depends on experience-based processes, further experiments on learning effect are needed [27].

The current study demonstrated the case where a certain visual process (biological motion perception) is tuned spatially (upright vs. inverted) and temporally (forward vs. backward) and that it is possibly shaped by experience. Domain-specific knowledge and information processing play important roles even in (apparently) primitive processes such as visual perception (including detection of human movements). Experience-based domain specific knowledge is traditionally considered as too vague to be analyzed systematically. However, recent advances in cognitive psychology provide stimuli and experimental paradigms that may be used for tackling

such vague senses, so called "kansei". Investigations on "kansei" could be facilitated by attaching importance to domain-specific (as oppose to generalized) processes and by obtaining empirical data supporting them. The present study can be considered as one such example from experimental psychology.

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