Time dilation caused by static images with implied motion

Yamamoto, Kentaro
Graduate School of Human-Environment Studies, Kyushu University | Faculty of Human-Environment Studies, Kyushu University

Miura, Kayo
Faculty of Human-Environment Studies, Kyushu University | Graduate School of Human-Environment Studies, Kyushu University

https://hdl.handle.net/2324/26295

出版情報：Experimental Brain Research. 223 (2), pp.311-319, 2012-10. Springer
バージョン：

Note: This is the author's version of a work publised at
Exp Brain Res (2012) 223:311-319

RESEARCH ARTICLE

Time dilation caused by static images with implied motion

Kentaro Yamamoto and Kayo Miura

K. Yamamoto
Graduate School of Human-Environment Studies, Kyushu University, 6-19-1 Hakozaki, Higashi-ku, Fukuoka-shi, Fukuoka 812-8581, Japan
E-mail: yama-ken@kyudai.jp

K. Miura
Faculty of Human-Environment Studies, Kyushu University, Fukuoka, Japan

---

Abstract The present study examined whether implicit motion information from static images influences perceived duration of image presentation. In Experiments 1 and 2, we presented observers with images of a human and an animal character in running and standing postures. The results revealed that the perceived presentation duration of running images was longer than that of standing images. In Experiments 3 and 4, we used abstract block-like images that imitated the human figures used in Experiment 1, presented with different instructions to change the observers' interpretations of the stimuli. We found that the perceived duration of the block image presented as a man running was longer than that of the image presented as a man standing still. However, this effect diminished when the participants were told the images were green onions (objects with no implied motion), suggesting that the effect of implied motion cannot be attributed to low-level visual differences. These results suggest that implied motion increases the perceived duration of image presentation. The potential involvement of higher-order motion processing and the mirror neuron system is discussed.

Keywords time perception, implied motion, static images, MT, mirror neuron

---

Introduction

Perception of brief event durations is critical for performing various activities, such as sports and locomotion. However, the duration of an event can sometimes be perceived as longer or shorter than its actual duration. Previous studies have shown that various visual features can distort subjective duration, including stimulus size (Thomas and Cantor 1975; Ono and Kawahara 2007), brightness (Xuan et al. 2007), number (Mo 1975; Xuan et al. 2007), complexity (Schiffman and Bobko 1974), and spatial frequency (Aaen-Stockdale et al. 2011). These reports suggest that multiple visual processing areas are involved in time perception.

Several studies have used moving stimuli to examine the involvement of visual processing areas in the dorsal pathway in time perception. It has been shown that the duration of fast-moving stimuli is perceived to last longer than the same duration of stationary or slow-moving stimuli (Brown 1995; Kanai et al. 2006; Yamamoto and Miura 2012). Moreover, Kaneko and Murakami (2009) revealed that stimulus speed, rather than temporal or spatial frequencies *per se*, is the determinant factor in motion-induced time dilation. The researchers suggest that higher order motion processing areas in the dorsal pathway, in which speed information is made explicit, play an important role in time perception (Kaneko & Murakami, 2009).

While these studies used physically moving objects as stimuli, images depicting action may also convey dynamic information, even though they do not physically change over time. The representation of movement in static images has been developed by artists, and several techniques for representing movement are found in their arts (Braddick 1995; Cutting 2002). Similar to real motion, substantial empirical evidence suggests that images involving implied motion are processed in higher cortical areas. For example, a series of static photographs involving implied motion in a particular direction produces a motion aftereffect in the opposite direction, suggesting that perception of implied motion activates direction-selective neurons that are also involved in processing real motion (Winawer et al. 2008). Moreover, functional magnetic resonance imaging (fMRI) studies have shown that action images with implied motion activate the human motion processing area MT+ more than images with little or no implied motion (Kourtzi and Kanwisher 2000; Lorteije et al. 2006; Osaka et al. 2010; Senior et al. 2000). Although it has been proposed that feedback (top-down) projections from higher-level form areas—such as the superior temporal sulcus—may contribute to the processing of implied motion in motion-selective regions (see Kourtzi et al. 2008), these results indicate that at least some common neural substrates underlie extraction of dynamic information from static images and moving objects.

The purpose of the present study was to examine whether implicit motion information from static images also influences the perceived duration of image presentation. Several studies have already examined the effect of implied dynamic information from static images on perceived duration (Nather and Bueno 2008, 2011; Nather et al. 2011; Moscatelli et al. 2011). However, there is a discrepancy between these reports, in that Moscatelli et al. (2011) used photographs of athletes to show that implied motion photographs did not differ in perceived duration from non-implied motion photographs. In contrast, a study using images depicting body posture showed that the perceived duration of a posture image implying clear movement was judged as longer than that of an image depicting little movement (Nather et al. 2011). This discrepancy may be related to differences in visual features between images that imply clear motion and images that imply slight motion. Although there are several techniques to imply motion in static images (Cutting 2002), these techniques involve changes in some low-level features of the images, such as shape, size, and body angle. The stimuli used in previous studies differed in the visual features of images involving clearly implied motion and those involving little implied motion. Because various visual features can also influence perceived duration (Aaen-Stockdale et al. 2011; Schiffman and Bobko 1974; Thomas and Cantor 1975; Xuan et al. 2007), these visual differences may have influenced the perceived duration and caused the discrepancies between these reports.

In the current study, we first compared perceived duration between images of a human and a wolf character involving clear implied motion or little implied motion. We then tested abstract block-like images that imitated the images of the human character, to test whether the differences in perceived duration between images with clearly implied motion and those with little implied motion can be attributed to differences in low-level visual features.

Experiment 1

Experiment 1 examined whether implied motion influences the perceived duration of image presentation, using images depicting a human character in a running posture (implying motion) and a standing posture (implying little motion). We used the temporal bisection task to measure the perceived duration of the image presentation (Gil and Droit-Volet 2009; Nather et al. 2011; Wearden and Ferrara 1996). In this task, observers were initially presented with a training stimulus with two standard durations, and they were instructed to categorize the presentation durations as “long” or “short”. After the participants learned to correctly categorize standard durations, they were presented with test stimuli of seven probe durations, and asked to judge whether the test duration was more similar to the long or short standard duration.

Methods

Observers

Ten naïve observers (5 men and 5 women, mean age = 22.60, *S.D.* = 3.81) participated in this experiment. All observers had normal or corrected-to-normal vision. Observers gave written informed consent in this and in all following experiments.

Apparatus

Stimuli were presented on a 17-inch CRT monitor with a 1,024 × 768 resolution at a refresh rate of 100 Hz. The monitor was gamma corrected. The presentation of stimuli and collection of data were computer-controlled (Mac Pro; Apple). A chin rest restrained the observer's head movements at a viewing distance of 57 cm. The stimuli were generated by Matlab (The MathWorks, Natic, MA, USA) with the Psychtoolbox extension (Brainard 1997; Pelli 1997).

Stimuli

The stimuli were displayed on a gray background. The training stimulus was a square object (7.1°×7.1°) composed of random colored noise. The test stimuli were images of a human character in a running or a standing posture (Figure 1a), created using Poser 6J software (e frontier America Inc., Tokyo, Japan). The images subtended visual angles of 6.4°–6.7° high. The size ratio obtained by dividing the size of the running image by that of the standing image was approximately 1.54.

Procedure

In all experiments, observers were individually tested in a dark room to eliminate artifact from ambient room lighting that can influence monitor brightness and time estimation (Xuan et al. 2007). Each experiment consisted of two phases, a training phase and a test phase. In the first phase (training phase), the training stimulus was presented with two standard durations (0.4 or 1.0 sec) after a 1 sec fixation display. Observers were asked to judge which standard duration ("long" or "short") was used for the target stimulus by pressing the "d" or "k" key. The response keys were

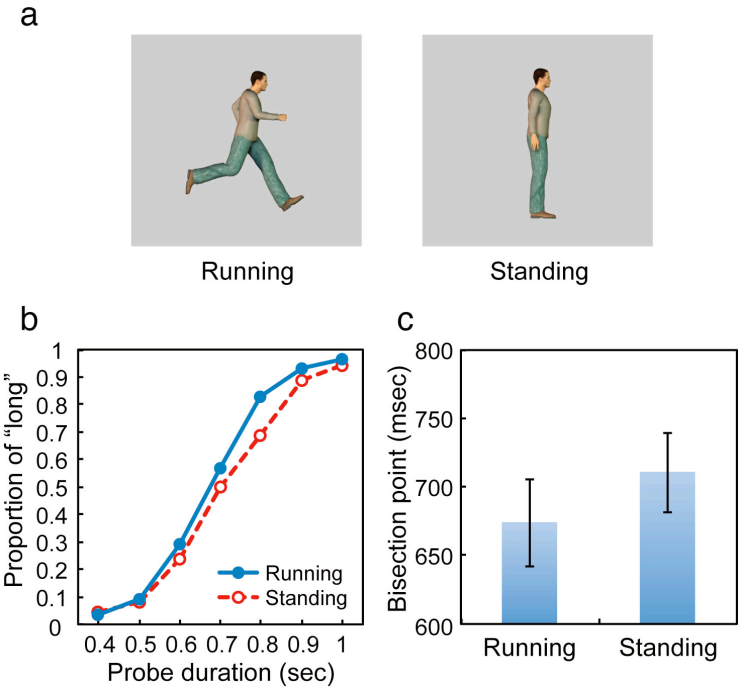

Fig. 1 Test stimuli and the results of Experiment 1. a The running and the standing posture images of the human character. b Proportion of long responses plotted against probe duration for each test stimulus. c Mean bisection points for each test stimulus.

counterbalanced across observers. After the observers responded, visual feedback ("true" or "false") was presented for 1 sec, and the trial was complete. Each observer was given successive blocks of 10 trials, consisting of five short standard duration trials and five long standard duration trials. The trial order was randomized across observers and across blocks. The training phase was terminated when observers completed 10 consecutive correct responses.

In the second phase (test phase), each test stimulus was presented with seven probe durations (0.4, 0.5, 0.6, 0.7, 0.8, 0.9, or 1.0 sec) after a 1-sec fixation display. The observers were asked to judge whether the probe duration was more similar to the long or to the short standard duration by pressing the corresponding key used in the training phase. No feedback was presented in this phase. Each observer completed 20 blocks and 280 trials in total. Half of the trials used right-facing images and the other half used left-facing images. The trial order was randomized across observers and across blocks.

Results and discussion

We first analyzed the proportion of long responses for each probe duration and test stimulus (Figure 1b). A two-way within-subject analysis of variance (ANOVA) revealed significant main effects of test stimulus ($F_{1, 9} = 11.87$, $p < 0.008$) and probe duration ($F_{6, 54} = 93.81$, $p < 0.001$), indicating that the proportion of long responses was higher for the running image than for the standing image, and the number of long responses increased with probe duration. In contrast, there was no significant interaction between the test stimulus and probe duration ($F_{6, 54} = 1.64$, $p > 0.15$).

We then calculated the bisection point, which is the stimulus duration giving rise to 50% long responses, to compare the mean perceived duration of the test stimuli. Cumulative Gaussian psychometric functions were fitted separately to the proportion of long responses for the standing and the running images using the psignifit toolbox for Matlab, which implements the maximum-likelihood method (Wichmann and Hill 2001a, 2001b). The goodness of fit was evaluated using the deviance and cumulative probability estimate (criteria: $p < 0.95$). The mean bisection point for each test stimulus is shown in Figure 1c. A paired *t*-test revealed that, consistent with the analysis of the proportion of long responses, the bisection point of the running image was significantly lower than that of the standing image ($t_9 = 3.52$, $p < 0.007$).

We also calculated the Weber ratio to analyze the temporal sensitivity to the images. This ratio is obtained by dividing the difference limen (half of the difference between the duration giving rise to 75% and 25% long responses) by the bisection point. A paired *t*-test showed no significant differences in the Weber ratio between the running and the standing images ($t_9 = 1.98$, $p > 0.078$).

These results revealed that the presentation duration of the image depicting a running posture was judged to be longer than that of the standing posture image. Consistent with Nather et al. (2011), our results suggest that the perceived duration of clearly implied motion images is longer than that of images implying little motion. By contrast, the Weber ratio did not differ between the test stimuli. This result is also consistent with Nather et al. (2011), suggesting that the temporal sensitivity of clearly implied motion images is no different from that of images implying little motion.

Experiment 2

Experiment 1 revealed that perceived duration was different between images with clearly implied motion and images with little implied motion of the human character. This finding is consistent with the results of Nather et al. (2011), in which images of human sculptures were used as stimuli. Experiment 2 was conducted to examine whether this effect can be generalized to impressions of motion induced by action images of non-human characters. Kourtzi and Kanwisher (2000) reported that implied motion images of animals activate the same human motion areas activated by images of humans. Therefore, we expected that perceived duration would be also different between images of non-human characters showing clearly implied motion and those with little implied motion. To address this possibility, we used images either depicting or not depicting movement of a wolf character, and compared the perceived presentation duration between them.

Methods

Observers

Eight naïve observers (3 men and 5 women, mean age = 23.63, *S.D.* = 3.42) participated in this experiment. One of them also participated in Experiment 1. All observers had normal or corrected-to-normal vision.

Apparatus, stimuli, procedure, and analysis

The apparatus, stimuli, procedure, and analysis used in Experiment 2 were identical to those in Experiment 1, except that the test stimuli were images of a wolf character in a running or a standing posture (Figure 2a), created using Poser 6J software. Although the angle of the body was slightly different between the test images, other low-level features were similar. The images subtended visual angles of 4.2°–4.4° high. The size ratio between the images was approximately 1.00.

Results and discussion

The mean proportion of long responses and the mean bisection point are shown in Figure 2b and 2c, respectively. A two-way within-subject ANOVA revealed that the proportion of long responses was marginally higher for the running image than for the standing image ($F_{1,7} = 5.74$, $p < 0.048$). There were also a significant main effect of probe duration ($F_{6,42} = 108.34$, $p < 0.001$) and a significant interaction between test stimulus and probe duration ($F_{6,42} = 2.61$, $p < 0.031$). An analysis of simple main effects based on the interaction revealed significant main effects of probe duration

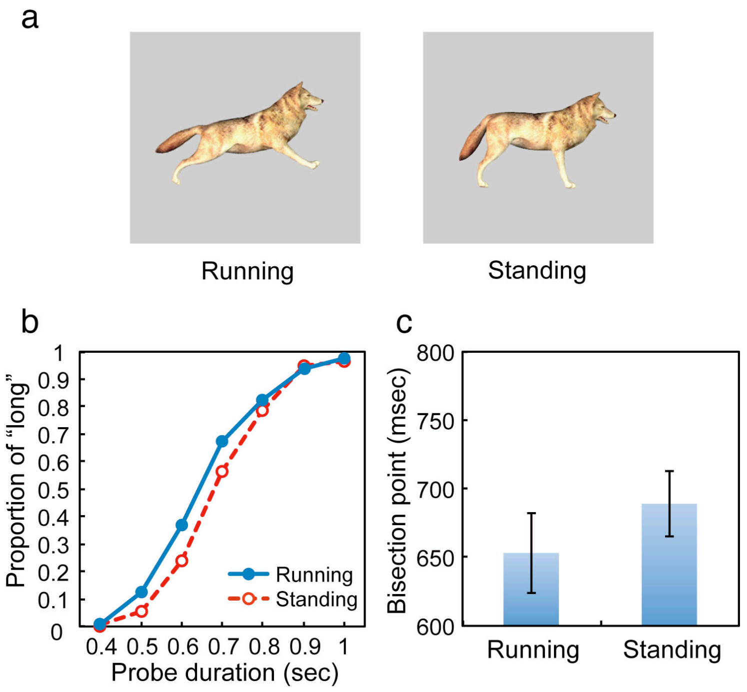

Fig. 2 Test stimuli and the results of Experiment 2. a The running and the standing posture images of the wolf character. b Proportion of long responses plotted against probe duration for each test stimulus. c Mean bisection points for each test stimulus.

in the running and the standing image conditions ($F_{6, 84} = 86.78$, $p < 0.001$; $F_{6, 84} = 94.371$, $p < 0.001$), and significant main effects of the test stimulus in the 0.6-s and the 0.7-s conditions ($F_{1, 49} = 11.76$, $p < 0.002$; $F_{1, 49} = 8.64$, $p < 0.006$). Moreover, paired *t*-tests revealed that the bisection point of the running image was significantly lower than that of the standing image ($t_7 = 3.52$, $p < 0.007$), whereas the Weber ratio was not significantly different between the test stimuli ($t_7 = 1.88$, $p > 0.092$).

These results revealed that, as in the case for the human character, the perceived presentation duration of the running posture image of the wolf character was longer than the standing posture image. This finding suggests that the effect of implied motion on perceived duration may not be limited to the impression of motion induced by human action images. In contrast, as in Experiment 1, we found no effect on temporal sensitivity.

Experiment 3

The results of Experiments 1 and 2 suggest that the perceived presentation duration of static images is affected by the impression of motion. However, there were some low-level visual differences between the running and the standing images in both experiments, and these differences may have influenced perceived duration. To address this question, in Experiment 3 we used block-like stimuli that imitated the running and the standing posture images of humans used in Experiment 1, and compared the perceived presentation duration between them. Although the finer details of these block-like stimuli differed from the original character images, low-level visual properties—such as stimulus size, shape, and body angle—were similar. If the difference in perceived presentation duration between images with clearly implied motion and those with little implied motion can be attributed to low-level visual differences, differences in perceived duration would also be observed between these block-like stimuli.

Methods

Observers

Fourteen naïve observers (6 men and 8 women, mean age = 22.43, *S.D.* = 3.27) participated in this experiment. None of them had participated in previous experiments in this study. All observers had normal or corrected-to-normal vision.

Apparatus, stimuli, procedure, and analysis

The apparatus, stimuli, procedure, and analysis used in Experiment 3 were identical to Experiment 1 except the test stimuli were block-like images (Figure 3a) created by placing rectangular blocks over the running and standing images used in Experiment 1. These stimuli were created using Adobe Photoshop (Adobe Systems, Inc., San Jose, CA, USA). The images subtended visual angles of 6.6°–6.7° high. The size ratio between the images was approximately 1.55. The colors of the body and leg parts of the test stimuli were selected from those parts of the character images in Experiment 1.

Although the stimuli used in this experiment were abstract block-like images, it was still possible that observers regarded the stimuli as human posture images, and for this to induce the impression of motion. To avoid this possibility, we explained to the observers that the test stimuli represented green onions (an object that does not imply motion) immediately before the test phase. We used green onions as our explanation because they are a popular vegetable in Japan and resembled the test stimuli in appearance. All observers unquestioningly accepted this information and did not recognize that the stimuli represented human postures during the experiment.

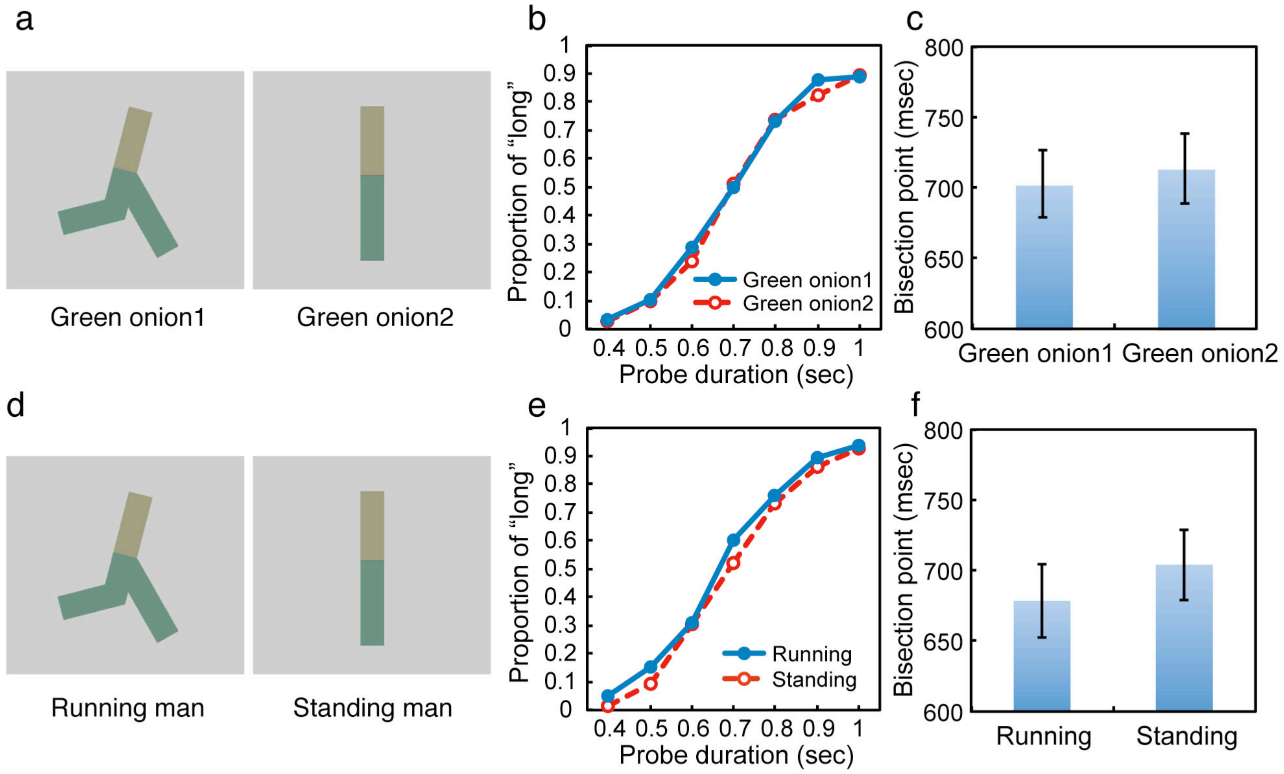

Fig. 3 Test stimuli and the results of Experiments 3 and 4. a, d The abstract block-like images that imitated the images of the human posture used in Experiment 1. The observers were told the images represented green onions (i.e., objects with no implied motion) in Experiment 3 and human postures in Experiment 4. b, e Proportion of long responses plotted against probe duration for each test stimulus. c, f Mean bisection points for each test stimulus.

Results and discussion

Data from one observer were excluded from further analysis because it failed a goodness of fit (deviance: $p > 0.95$). The mean proportion of long responses and the mean bisection point are shown in Figure 3b and 3c, respectively. A two-way within-subject ANOVA for the proportion of long responses showed a significant main effect of probe duration ($F_{6, 72} = 139.79$, $p < 0.001$). However, neither a main effect of test stimulus ($F_{1, 12} = 0.67$, $p > 0.42$) nor an interaction between test stimulus and probe duration ($F_{6, 72} = 0.77$, $p > 0.59$) was observed. Moreover, the bisection point and the Weber ratio were not significantly different between the test stimuli (bisection point: $t_{12} = 0.65$, $p > 0.53$; Weber ratio: $t_{12} = 0.43$, $p > 0.67$). These results revealed that the perceived presentation duration was not different between block-like images that imitated the posture images used in Experiment 1. This finding suggests that the differences in perceived duration observed in previous experiments cannot be attributed to the low-level visual differences.

Experiment 4

The purpose of Experiment 4 was to examine whether the same block-like images used in Experiment 3 influence perceived duration if observers regarded them as human posture images. A previous study revealed that abstract paintings with clearly implied motion disproportionately activated motion-sensitive area MT+ only when observers had prior experience of viewing these types of paintings and had received lectures on the depiction of motion in art (Kim and Blake 2007). Therefore, we predicted that the block-like images may influence perceived duration if the observers regarded them as human postures. To address this possibility, we measured the perceived presentation duration of the stimuli among the same participants, but changed the explanation of the test stimuli (Figure 3d).

Methods

Observers

Fourteen naïve observers participated in this experiment. All observers had also participated in Experiment 3.

Apparatus, stimuli, procedure, and analysis

The apparatus, stimuli, procedure, and analysis used in Experiment 4 were identical to Experiment 3 except that we explained to observers that the test stimuli represented the running and the standing postures of a human character, while displaying the images used in Experiment 1.

Results and discussion

The mean proportion of long responses and the mean bisection point are shown in Figure 3e and 3f, respectively. A two-way within-subject ANOVA revealed that the proportion of long responses was higher for the block image presented as a man running than for the image presented as a man standing still ($F_{1, 13} = 6.42$, $p < 0.03$). The main effect of probe duration was also significant ($F_{6, 78} = 102.72$, $p < 0.001$), but there was no significant interaction between test stimulus and probe duration ($F_{6, 78} = 1.09$, $p > 0.37$). Moreover, a paired *t*-test showed that the bisection point of the block image presented as a man running was significantly lower than that of the image presented as a man standing still ($t_{13} = 2.51$, $p < 0.03$). However, the Weber ratio was not significantly different between these test images ($t_{13} = 1.26$, $p > 0.22$).

These results suggest that, as in Experiments 1 and 2, the perceived presentation duration of static images with implied motion is longer than that of images with little implied motion. It should be noted that the perceived duration of the same stimuli was no different when the observers regarded the stimuli as depicting objects that did not imply motion in Experiment 3. These results strongly suggest that low-level visual differences between the stimuli cannot explain the perceived duration differences. In contrast, as in Experiments 1 and 2, the Weber ratio was no different between the test images, suggesting that temporal sensitivity was no different between clearly implied motion and images with little implied motion.

General Discussion

The present study examined whether implicit motion information from static images influences perceived presentation duration. We used the depictions of movement of human and animal characters, and found that images showing characters in a running posture were perceived to be presented for longer than images showing characters in a standing posture (Experiments 1 and 2). Moreover, we presented block-like images imitating human postures, and found that perceived presentation duration was no different between the block images when observers were told that they depicted objects that are not associated with motion (Experiment 3). In contrast, when the observers were told that the block images depicted a human figure, the perceived presentation duration was longer for those imitating a running character compared to those imitating a standing character (Experiment 4). These findings indicate that differences in perceived duration between images with clearly implied motion and images with little implied motion cannot be attributed to differences in low-level visual features between them. These results suggest that implied motion increases the perceived duration of a stimulus, which is similar to real motion.

Our results support the findings of Nather et al. (2011), showing that the perceived duration of a presented posture image depicting clear movement was longer than that of an image depicting little movement. However, it should be noted that Nather et al. used only images depicting human movements, whereas we used images of non-human characters, abstract block-like objects, and human-character images in the present study. This variety of stimuli allows us to consider whether the duration effect is limited by impressions of motion induced by particular kinds of images. That different kinds of static images similarly affected perceived duration suggests that the effects of implied motion are not limited to images of human-body postures. This is consistent with the previous results that motion-induced time dilation can be caused by a wide variety of moving objects (Brown 1995; Kanai et al. 2006; Kaneko and Murakami 2009; Yamamoto and Miura 2012).

Although this study and the study by Nather et al. (2011) found differences in perceived time between static images with and without implied motion, Moscatelli et al. (2011) reported that implied motion photographs did not differ in perceived duration from non-implied motion photographs. This discrepancy may be attributed to a difference in stimulus properties. The stimuli used in the current experiments and in the study of Nather et al were images of sculptures or computer generated characters that were composed of different postures of a human body, whereas Moscatelli et al. used naturalistic photographs of real people against real backgrounds. Naturalistic photographs have the advantage of leaving a vivid impression of the scenes they depict, but it is difficult to control visual features between them. In fact, although Moscatelli et al. matched some low-level (luminance and saliency) and high-level (sport, gender, and number of depicted athletes) features between the photographs with and without implied motion, other features were not adequately controlled. As discussed in Nather and Bueno (2012), the features of the background also influence time perception of static images. The differences in these features may have canceled out the effects of motion impressions.

In the studies of motion-induced time dilation, some researchers have suggested that spatial or luminance changes accompanying visual motion may cause time distortions. This idea is related to a change-based model (Block 1990; Fraisse 1963; Poynter 1989), in which the number of salient events is used as an index of the passage of time. However, Kaneko and Murakami (2009) revealed that time dilation depends not on temporal frequency but on speed, suggesting that this change is not the determinant factor of time distortion induced by motion. In line with their results, the present study revealed that time dilation also occurs with static images that do not physically change over time, but induce a perception of motion. These results suggest that the change-based model cannot fully explain motion-induced time dilation.

The results of Experiments 3 and 4 provide evidence that the effects of implied motion cannot be attributed to low-level visual differences, indicating that high-level visual information plays an important role in time distortion. Consistent with this idea, Ono and Kawahara (2007) showed that time distortion induced by visual size depends not on the physical size of the stimulus, but on the perceived size computed in higher visual processing stages. In addition, Curran and Benton (2012) demonstrated that adaptation-induced time distortion (Burr et al. 2007; Johnston et al. 2006) is caused by the adaptation of direction-selective neurons in higher motion processing areas. These results suggest that higher-level neural mechanisms are responsible for temporal processing of visual events.

Regarding the neural basis of the effect of implied motion on perceived duration, previous studies have demonstrated that action images with implied motion activate MT+ more than images with little or no implied motion (Kim and Blake 2007; Kourtzi and Kanwisher 2000; Lorteije et al. 2006; Osaka et al. 2010; Senior et al. 2000). Sadeghi et al. (2011) showed that both the duration and amplitude of the neural response in MT were positively correlated with the degree of novelty of the moving direction, suggesting that neural activity in MT contribute to temporal distortions. This result supports the recent models of time perception, which propose that the passage of time is estimated based on evolving patterns or the amount of neural activity (Eagleman and Pariyadath 2009; Ivry and Schlerf 2008; Mauk and Buonomano 2004). Moreover, recent transcranial magnetic stimulation studies showed that cortical areas around the right parietal lobe, including MT, are engaged in computing the timing of the onset and the offset of visual events (Battelli et al. 2008; Bueti et al. 2008). These studies indicate that activation in MT is involved in perceived duration differences between images with clearly implied motion and those with little implied motion. This is consistent with previous reports suggesting the importance of higher order visual processing in MT in motion-induced duration dilation (Kaneko and Murakami 2009; Yamamoto and Miura 2012), further suggesting that the same neural substrate is engaged in duration dilation induced by real or implied motion.

The effects of implied motion on perceived duration may also be mediated by the activation of motor cortex neurons involved in performing the actions depicted in the images. There is growing evidence that observing another's action activates the same neurons involved in execution of the action (Rizzolatti and Craighero 2004; Rizzolatti et al. 1996). These neurons, known as 'mirror neurons', are thought to respond not only when observing real actions, but also when observing static images depicting implied body actions (Proverbio et al. 2009; Urgesi et al. 2006). Based on these findings, Nather et al. (2011) proposed that human-posture images of large movements were judged to last longer because processing them involves the embodied simulation of more effortful movements, which is associated with greater arousal. This notion is in accord with the classical internal clock model (Gibbon 1977) and the effects of arousal on the speed of the internal clock (Droit-Volet and Wearden 2002; Penton-Voak et al. 1996).

Although it is difficult to determine which explanation is more plausible, it should be noted that differences in perceived duration between images with clearly implied motion and images with little implied motion were observed in pictures of non-human characters. There have been studies suggesting that motor-cortex activation is related to the observer's ability to understand and imitate motor acts. For example, observation of artificial hand actions has been reported to evoke less activity in the mirror system than real hand actions (Perani et al. 2001; Tai et al. 2004), and observation of non-goal-directed tool use also evoked less activity in this system than goal-directed actions (Jarvelainen et al. 2004). These reports indicate that if the effect of implied motion on perceived duration is mediated by mirror neurons, the effect should diminish or decrease with non-human-like character images. However, we found a comparable effect for the human (Experiment 1) and wolf characters (Experiment 2). This finding suggests that higher order visual processing, rather than the mirror neuron system, is more likely to be involved in the differences in perceived duration between images involving clearly implied motion, and those with little implied motion. However, for animated implied motion, the mirror neuron system may have some role in processing implied motion in motion-selective regions, suggesting that both higher order visual processing and mirror neuron system played a role in the time dilation observed in the present study. Future studies using inanimate implied motion images should be conducted to clarify the role of the mirror neuron system.

Acknowledgments This work was supported by a Grant-in-Aid for JSPS Fellows #224466 to K.Y. and Grants-in-Aid for Scientific Research #20330153 to K.M. from the Japan Society for the Promotion of Science (JSPS).

References

Aaen-Stockdale C, Hotchkiss J, Heron J, Whitaker D (2011) Perceived time is spatial frequency dependent. Vis Res 51(11):1232–1238

Block RA (1990) Models of psychological time. In: Block RA (ed) Cognitive Models of psychological time. Lawrence Erlbaum, Hillsdale, New Jersey, pp 1–35

Battelli L, Walsh V, Pascual-Leone A, Cavanagh P (2008) The 'when' parietal pathway explored by lesion studies. Curr Opin Neurobiol 18(2):120–126

Braddick O (1995) The Many Faces of Motion Perception. In: Gregory R, Harris J, Heard P, Rose D (eds) The Artful Eye. Oxford University Press, Oxford, pp 205–231

Brainard DH (1997) The Psychophysics Toolbox. Spat Vis 10(4):433–436

Brown SW (1995) Time, change, and motion: the effects of stimulus movement on temporal perception. Percept Psychophys 57(1):105–116

Bueti D, Bahrami B, Walsh V (2008) Sensory and association cortex in time perception. J Cogn Neurosci 20(6):1054–1062

Burr D, Tozzi A, Morrone MC (2007) Neural mechanisms for timing visual events are spatially selective in real-world coordinates. Nat Neurosci 10:423–425

Curran W, Benton CP (2012) The many directions of time. Cognition 122:252–257

Cutting JE (2002) Representing motion in a static image: constraints and parallels in art, science, and popular culture. Perception 31(10):1165–1193

Droit-Volet S, Wearden JH (2002) Speeding up an internal clock in children? Effects of visual flicker on subjective duration. Q J Exp Psychol 55B:193–211

Eagleman DM, Pariyadath V (2009) Is subjective duration a signature of coding efficiency? Phil Trans R Soc B 364:1841–1851

Fraisse P (1963) The psychology of time. Harper & Row, New York

Gibbon J (1977) Scalar expectancy theory and Weber’s law in animal timing. Psychol Rev 84(3):279–325

Gil S, Droit-Volet S (2009) Time perception, depression and sadness. Behav Processes 80(2):169–176

Ivry RB, Schlerf JE (2008) Dedicated and intrinsic models of time perception. Trends Cogn Sci 12:273–280

Jarvelainen J, Schurmann M, Hari R (2004) Activation of the human primary motor cortex during observation of tool use. Neuroimage 23(1):187–192

Johnston A, Arnold DH, Nishida S (2006) Spatially localized distortions of event time. Curr Biol, 16, 472–479

Kanai R, Paffen CL, Hogendoorn H, Verstraten FA (2006) Time dilation in dynamic visual display. J Vis 6(12):1421–1430

Kaneko S, Murakami I (2009) Perceived duration of visual motion increases with speed. J Vis 9(7):14 1–12

Kim C-Y, Blake R (2007) Seeing what you understand: Brain activity accompanying perception of implied motion in abstract paintings, Spat Vis 20(6):545–560

Kourtzi Z, Kanwisher N (2000) Activation in human MT/MST by static images with implied motion. J Cogn Neurosci 12(1):48–55

Kourtzi Z, Krekelberg B, van Wezel RJA (2008) Linking form and motion in the primate brain. Trends Cogn Sci 12(6):230–236

Lorteije JA, Kenemans JL, Jellema T, van der Lubbe RH, de Heer F, van Wezel RJ (2006) Delayed response to animate implied motion in human motion processing areas. J Cogn Neurosci 18(2):158–168

Mo SS (1975) Temporal reproduction of duration as a function of numerosity. Bull Psych Soc 5(2):165–167

Mauk MD, Buonomano DV (2004) The neural basis of temporal processing. Annu Rev Neurosci 27:307–330

Moscatelli A, Polito L, Lacquaniti F (2011) Time perception of action photographs is more precise than that of still photographs. Exp Brain Res 210(1):25–32

Nather FC, Bueno JLO (2008) Movement ranking scale of human body static images for subjective timing estimation. Proceedings of the 24th Annual Meeting of the Society for Psychophysics, pp 185–190

Nather FC, Bueno JLO (2011) Static images with different induced intensities of human body movements affect subjective time. Percept Motor Skills 113(1):157–170

Nather FC, Bueno JLO (2012) Timing perception in paintings and sculptures of Edgar Degas. KronoScope 12(1):16–30

Nather FC, Bueno JLO, Bigand E, Droit-Volet S (2011) Time changes with the embodiment of another’s body posture. PLoS One 6(5):e19818

Ono F, Kawahara J (2007) The subjective size of visual stimuli affects the perceived duration of their presentation. Percept Psychophys 69(6):952–957

Osaka N, Matsuyoshi D, Ikeda T, Osaka M (2010) Implied motion because of instability in Hokusai Manga activates the human motion-sensitive extrastriate visual cortex: an fMRI study of the impact of visual art. Neuroreport 21(4):264–267

Pelli DG (1997) The VideoToolbox software for visual psychophysics: Transforming numbers into movies. Spat Vis 10(4):437–442

Penton-Voak IS, Edwards H, Percival A, Wearden JH (1996) Speeding up an internal clock in humans? Effects of clicks trains on subjective duration. J Exp Psychol: Anim Behav Process 22(3):307–320

Perani D, Fazio F, Borghese NA, Tettamanti M, Ferrari S, Decety J, Gilardi MC (2001) Different brain correlates for watching real and virtual hand actions. Neuroimage 14(3):749–758

Perrone JA, Thiele A (2001) Speed skills: Measuring the visual speed analyzing properties of primate MT neurons. Nat Neurosci, 4(5):526–532

Poynter D (1989) Judging the duration of time intervals: A process of remembering segments of experience. In: Levin I & Zakay D (eds) Time and human cognition: A life-span perspective. Elsevier, The Netherlands, pp 305–321

Proverbio AM, Riva F, Zani A (2009) Observation of Static Pictures of Dynamic Actions Enhances the Activity of Movement-Related Brain Areas. PLoS ONE 4(5):e5389

Rizzolatti G, Craighero L (2004) The mirror-neuron system. Annu Rev Neurosci 27:169–192

Rizzolatti G, Fadiga L, Gallese V, Fogassi L (1996) Premotor cortex and the recognition of motor actions. Cogn Brain Res 3(2):131–141

Ryan TA (1960) Significance tests for multiple comparison of proportions, variances, and other statistics. Psychol Bull, 57(4):318–328

Sadeghi NG, Pariyadath V, Apte S, Eagleman DM, Cook EP (2011) Neural correlates of subsecond time distortion in the middle temporal area of visual cortex. J Cogn Neurosci 23(12):3829–3840

Senior C, Barnes J, Giampietro V, Simmons A, Bullmore ET, Brammer M, David AS (2000) The functional neuroanatomy of implicit-motion perception or representational momentum. Curr Biol, 10(1):16–22

Schiffman HR, Bobko DJ (1974) Effects of stimulus complexity on the perception of brief temporal intervals. J Exp Psychol, 103(1):156–159

Tai YF, Scherfler C, Brooks DJ, Sawamoto N, Castiello U (2004) The human premotor cortex is ‘mirror’ only for biological actions. Curr Biol 14(2):117–120

Thomas EAC, Cantor NE (1975) On the duality of simultaneous time and size perception. Percept Psychophys 18(1):44–48

Urgesi C, Moro V, Candidi M, Aglioti SM (2006) Mapping implied body actions in the human motor system. J Neurosci 26(30):7942–7949

Wearden JH, Ferrara A (1996) Stimulus range effects in temporal bisection by humans. Q J Exp Psychol 49B:24–44

Wichmann FA, Hill NJ (2001a) The psychometric function: I. Fitting, sampling, and goodness of fit. Percept Psychophys 63(8):1293–1313

Wichmann FA, Hill NJ (2001b) The psychometric function: II. Bootstrap-based confidence intervals and sampling. Percept Psychophys 63(8):1314–1329

Winawer J, Huk AC, Boroditsky L (2008) A motion aftereffect from still photographs depicting motion. Psychol Sci 19(3):276–283

Xuan B, Zhang D, He S, Chen X (2007) Larger stimuli are judged to last longer. J Vis 7(10):2 1–5

Yamamoto K, Miura K (2012) Perceived duration of plaid motion increases with pattern speed rather than component speed. J Vis 12(4):1 1–13