Research Report

Fitts's Law Holds for Action Perception

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ABSTRACT—*Fitts's law is one of the most well-established principles in psychology. It captures the relation between speed and accuracy in performed and imagined movements. The aim of this study was to determine whether this law also holds during the perception of other people's actions. Subjects were shown apparent motion displays of a person moving his arm between two identical targets. Target width, the separation between targets, and movement speed were varied. Subjects reported whether the person could move at the perceived speed without missing the targets. The movement times reported as being just possible were exactly those predicted by Fitts's law ($r^2 = .96$). A subsequent experiment demonstrated the same lawful relation for the perception of a robot arm ($r^2 = .93$). To our knowledge, this makes Fitts's law the first motor principle that holds in imagery and the perception of biological and nonbiological agents.*

A growing body of recent research has sparked renewed interest in the links between action production, motor imagery, and action perception (Blakemore & Decety, 2001; Jeannerod, 2001; Rizzolatti & Craighero, 2004; Viviani, 2002; Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003). For example, Decety and Jeannerod (1995) emphasized that imagining a particular action relies on the same cognitive and neural processes as performing that action, much as visual imagery uses perceptual systems (Kosslyn, 1994). Along similar lines, Prinz (1997; see also Decety & Grèzes, 1999) has claimed that action perception and action production rely on a common representational system. Numerous neurophysiological findings, such as the selective activation of motor and parietal cortices during action perception (e.g., Stevens, Fonlupt, Shiffrar, & Decety,

2000) and the existence of mirror neurons (e.g., Rizzolatti & Craighero, 2004), support this proposal.

At a processing level, simulation (emulation) theories (Grush, 2004; Jeannerod, 2001; Wilson & Knoblich, 2005) posit the existence of internal models that act as predictors for action outcomes. During performance of an action, the perceptual consequences of that action are automatically predicted. In "off-line" modes, the same models can be used for generating imagery and perceptual expectations in the absence of concurrent action production.

At their core, these accounts predict that the principles governing movement production should also constrain motor imagery and action perception. Here we show that Fitts's law, which defines speed-accuracy trade-offs in movement production and motor imagery, also holds for action perception. This finding closes the loop relating action production, motor imagery, and action perception, because, to our knowledge, no other motor phenomenon has been studied in all three domains.

Fitts's law (Fitts, 1954) states that the time needed to move as quickly as possible between two targets is determined by the width of the targets and the distance separating them:

$$MT = a + b \cdot ID,$$

where MT is movement time, ID is the index of difficulty of the movement, and a and b are empirical constants. The critical variable is ID, which relates the amplitude (A) of the movement to the width (W) of the targets:

$$ID = \log_2(2 \cdot A/W).$$

Fitts's law is one of the most robust and well-studied principles of human movement (for review, see Plamondon & Alimi, 1997). With very few exceptions (e.g., Chi & Lin, 1997; Danion, Duarte, & Grosjean, 1999), this relation between MT and ID has been shown to hold for different movements, effectors, and movement contexts.

Decety and Jeannerod's (1995) demonstration that Fitts's law holds for imagined movements was an important breakthrough because it showed that motor constraints influence imagery. In

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the present study, we addressed whether this relation also holds for the perception of other people's actions (Experiment 1) and whether it is restricted to the observation of the human body (Experiment 2). The second experiment allowed us to determine whether the same motor constraints govern the perception of movements of biological and nonbiological agents.

EXPERIMENT 1

In an apparent motion paradigm, subjects viewed two alternating pictures of a person moving at various speeds between two targets that varied in amplitude and width. Subjects reported whether the person could perform such movements without missing the targets. We chose alternating pictures instead of videos to avoid any influence of movement trajectory cues, which are not addressed by Fitts's law. Perceived MT was defined as the speed at which subjects provided an equal proportion of "possible" and "impossible" judgments. If Fitts's law applies to action perception, then perceived MTs would be expected to be linearly related to the ID of the observed movements.

Method

Subjects
Twenty people (age range: 20–35 years) were paid for their participation. All subjects reported normal or corrected-to-normal vision and were naive as to the purpose of the study.

Apparatus, Stimuli, and Responses
Stimulus presentation and response registration were controlled by a G3 PowerPC Macintosh that was running PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) and was connected to a 20-in. Apple ColorSync monitor (1024 × 768 pixels; 75 Hz). The stimuli consisted of pairs of full-colored digital photographs of the arms and torso of a person sitting at a table on which two targets were placed. In each picture pair, the person was pointing at the center of the left target in one picture and at the center of the right target in the other picture. The two targets had identical widths and were separated (center to center) by a given amplitude. Across trials, each of three widths (2, 4, and 8 cm) was combined with three of five amplitudes (4, 8, 16, 32, or 64 cm), so that three IDs (2, 3, and 4) were tested for each width. Figure 1 (two upper panels) presents sample stimuli that have identical IDs but different widths and amplitudes.

The stimuli were presented at the center of the monitor and were 21.70 × 14.90 cm (width × height) in size. Given an approximate viewing distance of 60 cm, the stimuli subtended 20.50° × 14.16° of visual angle. Responses were made by pressing either a left button (labeled "possible") or a right button (labeled "impossible") on the PsyScope Button Box (New Micros Inc., Dallas, TX).
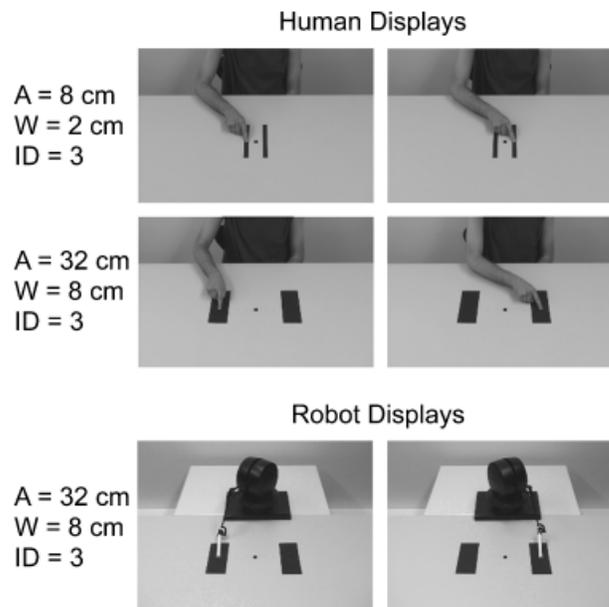
Fig. 1. Sample stimuli depicting human movement (Experiment 1) and robot movement (Experiment 2) with different combinations of movement amplitude (A) and target width (W) leading to identical indices of difficulty (IDs). The pictures used in the experiments were in color.

Procedure and Design
Written instructions informed subjects that they would see a person moving his hand back and forth between two targets. Their task was to judge whether they thought it was possible or impossible for the person to move that fast without missing the targets. Subjects were instructed to keep both of their hands on the button box at all times.

Each trial of the experiment involved an apparent motion display of alternating paired pictures with one of the nine combinations of width (2, 4, or 8 cm) and ID (2, 3, or 4). The rate at which the stimuli alternated was set at 1 of 16 stimulus-onset asynchronies (SOAs), which also corresponded to the individual stimulus durations. SOAs ranged from 120 through 720 ms in 40-ms increments and were chosen so that they spanned the mean MTs (200–600 ms) generally found in experiments requiring cyclical arm movements between targets defined by the IDs used here (Plamondon & Alimi, 1997). Each apparent motion display was presented until the subject made a judgment. Subjects were encouraged to take as much time as they needed to make their judgments.

After six practice trials, subjects performed three experimental blocks. In each block, each of the 144 possible trial types (3 widths × 3 IDs × 16 SOAs) was presented once in a pseudorandom order that varied from block to block.

Data Analysis
The proportion of "possible" judgments was computed for each SOA, width-ID combination, and subject. For a given combination and subject, the proportion of "possible" judgments
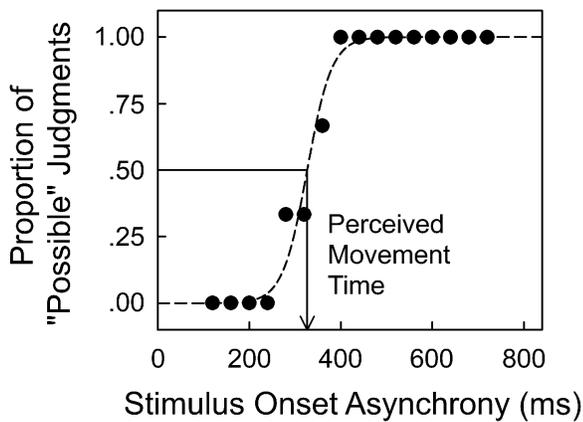
Fig. 2. Proportion of "possible" judgments as a function of stimulus onset asynchrony for one condition (combination of index of difficulty and width) and subject in Experiment 1. The best-fitting logistic function and a depiction of how perceived movement time was defined are also provided.

increased in a sigmoidal fashion with SOA, as illustrated in Figure 2. To determine what we defined as perceived MT, we fit a logistic function of the form $y = 1/(1 + e^{(a-x)/b})$ to these data using maximum-likelihood estimation. Perceived MT was then defined as the SOA that corresponded to a proportion of .5 "possible" judgments. In other words, perceived MT corresponded to the SOA at which subjects made the transition from saying "impossible" to saying "possible." To test whether the data were in accordance with Fitts's law, we submitted the mean perceived MTs (across subjects) to a linear regression analysis with ID as the predictor variable.

Results and Discussion

A total of 0.57% of trials was lost because of recording errors. For 5 subjects, the logistic function for at least one width-ID combination ($M = 2.80$) could not be fit. The perceived MTs for those combinations could not be defined because the movements were judged as possible at all SOAs. Missing perceived MTs for a given subject were replaced with the overall mean perceived MT for that subject. This procedure works against the predictions of Fitts's law.

Figure 3a presents mean perceived MT as a function of width and ID. The results are consistent with Fitts's law: Perceived MTs increased linearly with ID. The regression analysis yielded a significant r^2 of .96, $F(1, 7) = 162.19$, $p_{rep} > .99$, and the following regression equation: perceived $MT = 56 + 74 \cdot ID$. These results demonstrate that Fitts's law holds for action perception.

EXPERIMENT 2

Does Fitts's law also hold for the perception of movements of nonbiological agents? Previous studies suggest that the same motor constraints can govern the perception of biological and
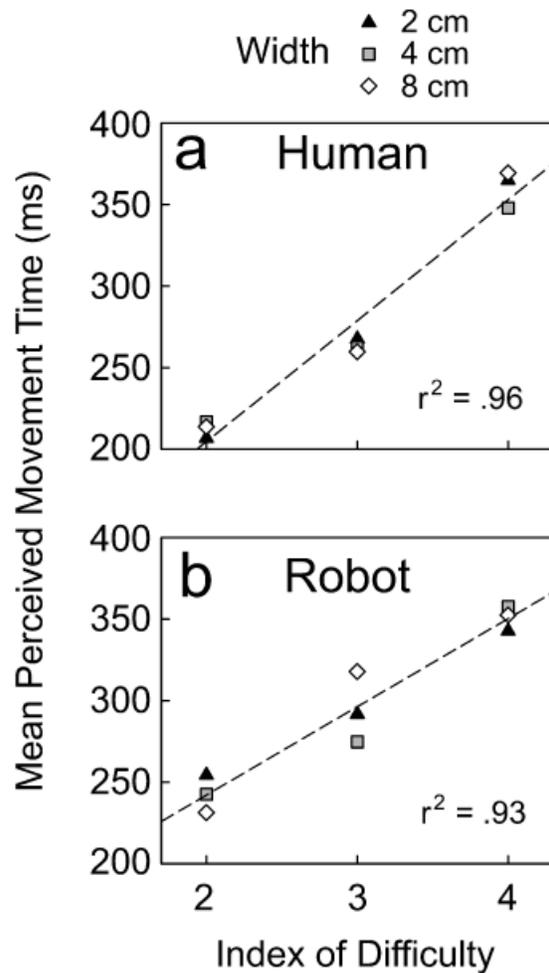
Fig. 3. Mean perceived movement time as a function of index of difficulty and width for (a) the human movement in Experiment 1 and (b) the robot movement in Experiment 2. Also shown are the corresponding linear regression lines and coefficients of determination.

nonbiological agents. For example, Heptulla-Chatterjee, Freyd, and Shiffrar (1996) showed that paths of apparent motion were perceived as biological when pictures of a wooden mannequin were used. Press, Bird, Flach, and Heyes (2005) found evidence of an automatic tendency to imitate hand postures of a robot, albeit to a lesser degree than human postures are imitated (but see Castiello, Lusher, Mari, Edwards, & Humphreys, 2002). Accordingly, Viviani (2002) has proposed that humans adopt biological motion as the default model for dynamic perception.

To test whether motor constraints can influence the perception of nonbiological agents, we performed a second experiment in which we replaced the human arm with a robot that shared some structural properties with human arms. The task of judging the possible accuracy of the movements of a robot might seem awkward because subjects generally do not have experience watching robots. Nonetheless, it allowed us to assess whether perception of movements by a nonbiological agent is constrained by Fitts's law.

Method

A new group of 20 individuals (age range: 19–28 years) participated. The method was identical to that of Experiment 1 except that the human model was replaced with a PHANTOM robot (SensAble Technologies Inc., Woburn, MA). The pointing movements of the human were matched by positioning the tip of the robot's "arm" at the centers of the left and right targets in each picture pair (see the bottom panel of Fig. 1). Subjects judged whether it was "possible" or "impossible" for the robot to move at the presented speed without missing the targets. We emphasized to the subjects that they should base their judgments on their own intuition of what the robot could or could not do.

Results and Discussion

A total of 0.35% of trials was discarded because of recording failures. Two subjects were completely excluded from the analysis because the logistic function could not be fit to their data for any of the width-ID combinations. For 4 subjects, the perceived MT for at least one combination ($M = 3.25$) could not be defined. These missing values were replaced using the same procedure as in Experiment 1.

Figure 3b presents mean perceived MT as a function of width and ID. Although the data pattern was slightly less clear-cut than in Experiment 1, perceived MTs again increased linearly with ID. The regression analysis produced a significant r^2 of .93, $F(1, 7) = 92.20$, $p_{rep} > .99$, and the following regression equation: perceived $MT = 133 + 54 \cdot ID$.

Therefore, Fitts's law also holds for the perception of nonbiological agents, at least when they share basic structural properties with the human body. However, it is possible that the effects of width and ID on perceived MTs were not the same for the robot pictures as for the human pictures. To test this possibility, we performed a three-way mixed-factor analysis of variance on perceived MTs, with width and ID as within-subjects factors and agent (human, robot) as a between-subjects factor. The only effect to reach significance was the main effect of ID (Greenhouse-Geisser corrected) $\varepsilon = .60$, $F(2, 72) = 46.92$, $p_{rep} > .99$, $\eta_p^2 = .57$ (all other $p_{rep}s < .83$). The absence of any effects involving agent suggests that there was no difference in the way human motions and robot motions were perceived. Moreover, the fact that the analysis of variance yielded only a highly significant main effect of ID rules out the possibility that the results of the regression analyses in Experiments 1 and 2 were an artifact of cross-subject averaging.

GENERAL DISCUSSION

The current results clearly show that Fitts's law holds for the visual perception of actions produced by human and nonbiological agents. However, some potential alternative interpretations need to be considered. First, subjects may have performed the tasks by monitoring the speed of their own eye movements while saccading between targets as quickly as possible. However, Fitts's law does not apply to saccadic eye movements (Chi & Lin, 1997). Although saccadic MTs increase with movement amplitude, they also increase with target width. The latter is a clear violation of Fitts's law.

Second, the perceived MTs could reflect Korte's third law (Korte, 1915; see also Hartman, 1981; Kolers, 1972). This law states that as one increases the spatial separation between two objects, the time between successive displays also needs to be increased to afford the most vivid apparent motion. This law predicts an effect of movement amplitude, but not of target width. However, ID accounted for almost all the variance in perceived MTs.

Third, it could be argued that the present results provide another, albeit novel, example of motor imagery, rather than action perception. Subjects could have observed the movements and subsequently imagined performing the movements at the same tempo. However, Shepard and Cooper (1982) have pointed out that active imagery is more effortful than apparent motion perception. It seems unlikely that subjects would have chosen an effortful approach when there was an easier one. Most important, the motions were presented until the subjects made their judgment and therefore would have interfered with any active form of imagery.

We believe the present findings close the loop relating action production, motor imagery, and action perception. To our knowledge, no other fundamental motor law has been shown to hold for both motor imagery and action perception. To be sure, numerous studies have revealed overlapping neural systems for these three domains (Blakemore & Decety, 2001; Grèzes & Decety, 2001; Rizzolatti & Craighero, 2004). Nonetheless, it is important to validate the interpretation of neural data with functional similarities.

It will be interesting to see whether the loop can be closed for other principles of motor control that have already been investigated in two of the three domains. Examples include the relationship between movement curvature and movement speed (Viviani & Stucchi, 1992) and the stability of phase relationships in bimanual coordination (Zaal, Bingham, & Schmidt, 2000). Exploring such phenomena should help to directly relate neural activation to motor constraints.

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