THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2009, 62 (11), 2210–2221

Psychology Press
Taylor & Francis Group

The limits of visual mass perception

Jaeho Shim
Baylor University, Waco, TX, USA

Heiko Hecht
Johannes Gutenberg-Universität Mainz, Mainz, Germany

Jung-Eun Lee and Dong-Won Yook
Yonsei University, Seoul, South Korea

Ji-Tae Kim
Dankook University, Yong-In, South Korea

The theory of direct perception suggests that observers can accurately judge the mass of a box picked up by a lifter shown in a point-light display. However, accurate perceptual performance may be limited to specific circumstances. The purpose of the present study was to systematically examine the factors that determine perception of mass, including display type, lifting speed, response type, and lifter's strength. In contrast to previous research, a wider range of viewing manipulations of point-light display conditions was investigated. In Experiment 1, we first created a circumstance where observers could accurately judge lifts of five box masses performed by a lifter of average strength. In Experiments 2–5, we manipulated the spatial and temporal aspects of the lift, the judgement type, and lifter's strength, respectively. Results showed that mass judgement gets worse whenever the context deviates from ideal conditions, such as when only the lifted object was shown, when video play speed was changed, or when lifters of different strength performed the same task. In conclusion, observers' perception of kinetic properties is compromised whenever viewing conditions are not ideal.

Keywords: Visual perception; Point-light; Lifting motion; Heuristics; Kinematics.

Marey's (1895/1972) chronophotographs, where he attached shiny buttons to the joints of actors and connected them with shiny wires, was the original work that produced point-light displays. Later, Johansson (1950, 1973) popularized the use of this technique and demonstrated that perception of biological motion is possible merely on the basis of the kinematic information contained in the body joints marked by point-lights. Such displays have proven to be helpful in diagnosing the relevant aspects of visual information that guides dynamic judgements and action. In the present study, we manipulated the context, the richness, and the velocity of this kinematic information, along with the type of judgement to assess how observers judge the mass of lifted objects. In contrast to the existing literature, observers often fail to consistently achieve accurate judgements of mass. We explored potential reasons for this discrepancy.

Correspondence should be addressed to Jaeho Shim, Baylor University, Department of Health, Human Performance, & Recreation, P.O. Box 97313, Waco, TX 76798, USA. E-mail: joe_shim@baylor.edu

http://www.psypress.com/qjep
DOI:10.1080/17470210902730597

It is uncontested that point-light displays allow observers to recognize qualitative aspects of biological motion, such as a walker's gender (Barclay, Cutting, & Kozlowski, 1978; Cutting, 1978; Kozlowski & Cutting, 1977; Runeson & Frykholm, 1983) and the identity of a friend's walking pattern (Cutting & Kozlowski, 1977). Researchers focused on what causes observers to perceive such rich information from rather impoverished displays of movement without texture and colour. For example, Todd (1983) demonstrated that perception of gait is primarily determined by the movements of the lower leg. Cutting (1978) hypothesized that the gender of a walker is perceived from the centre of moment, which is specified by the shoulder and hip arc.

Researchers were also interested in the cause-and-effect relationship between the kinematics of movement and the perceptual property upon which it is based. They investigated how mass ratio can be judged when viewing two colliding bodies and how merely watching a person lift a box can inform estimation of box mass (Bingham, 1987; Runeson & Frykholm, 1981; Shim, Carlton, & Kim, 2004). Runeson and his coworkers (Runeson, 1995; Runeson & Frykholm, 1981; Runeson & Vedeler, 1993) have used the kinematic specification of dynamics (KSD) approach to argue that in both colliding objects and lifted mass, observers can directly perceive kinetic properties (i.e., mass or weight) from kinematics (e.g., displacement, velocity, and acceleration of the joints) as long as the kinetics of an event are sufficiently specified by its kinematics. On the other hand, Gilden and Proffitt's (Gilden & Proffitt, 1989, 1994; Proffitt & Gilden, 1989) heuristics approach to perception challenged the suggestion that observers can directly perceive kinetics from kinematics. The heuristics approach holds that people use heuristics or rules to infer properties associated with kinematic patterns. Observers make inaccurate judgements of event properties whenever they apply inadequate rules or when they do not have any learned rules that they can relate to the event.

Thus, if rules that generally hold are violated, performance should break down if judgements are based on these rules but not so if the visual system is directly attuned to kinetic properties. Note that while a decisive experiment between the two approaches may be impossible (see Hecht, 1996), it would be a strong support for the direct approach if performance remains high when typical constraints of point-light motion are removed. In comparatively constant contexts, such as lifter strength, movement speed, and so on, Runeson and Frykholm (1981) and Bingham (1993) have shown accurate mass estimation by observers. Likewise, Shim and Carlton (1997) found mass estimates to be accurate when context variables were held constant, both when observing an individual perform other tasks (e.g., carrying the box) in addition to the lift and when observing the lift alone. In the same study, however, it was also shown that observers underestimated the 20-kg box by more than 5 kg when the box was lifted by four individuals of different size and gender. In Shim, Carlton, and Kim's (2004) study, an underestimation of mass was even greater when a much heavier 64-kg box was estimated. The weight of lighter boxes, in contrast, tended to be overestimated in Runeson and Frykholm's (1981) study and in Bingham's (1993) study. This overestimation of light mass was also found in a simpler lifting motion of arm curl (Bingham, 1987).

In order to obtain systematic insight into the conditions of accurate and erroneous perception of mass, we first replicated Runeson and Frykhom's (1981) and Bingham's (1993) findings in Experiment 1 and then manipulated the spatial and temporal aspects, judgement type, and lifter's strength in Experiments 2–5.

EXPERIMENT 1: REPLICATING ACCURATE PERFORMANCE

To find out whether observers are quantitatively accurate in estimating mass of lifted objects only when context information is available, we first needed to establish a reference task where performance was indeed accurate. In Runeson and

Frykholm's (1981) study observers were indirectly informed about the lifter and mass in various ways. Without variability in lifter size, observers perhaps estimated masses corresponding to the average-size lifter. The lifter in Runeson and Frykholm's study may have fallen near this average. Bingham (1993) tested different-size lifters and showed that the mass estimation values still corresponded closely to the actual mass. Bingham's observers merely had the opportunity to learn more about the lifter and mass by actually lifting a box of standard mass and then by seeing an individual lift the same box. Thus, our reference task was modelled after this study.

Accordingly, in Experiment 1, we attempted to replicate Bingham's findings. We used pieces of retroreflective tape to generate point-lights, used five masses, and gave observers haptic experience and display of a standard mass lift that matched the design of the first experiment in Bingham's (1993) study with the only exception that a somewhat wider box and a somewhat shorter and lighter lifter were used.

Method

Participants

A total of 18 participants (12 men and 6 women, age = 20 ± 1.3 years) were selected. Observers had no previous experience with the point-light display, and they all signed informed consent forms.

Stimuli and apparatus

One lifter (height = 1.75 m, mass = 61 kg) participated. A S-VHS (Panasonic AG-455, 60 Hz) video camera was used to record the motions of the lifter, and a Sharp LCD projector (Notevision 2SB, brightness = 1,400 ANSI lumens) was used to project the recorded and edited lifts on a large screen (2 m × 2 m) for observers to view.

Point-light displays were generated by using pieces of retroreflective tape (2.5 cm wide). A total of 13 pieces of retroreflective tape were attached to the head and both the left and right sides of the six major joints of arms and legs. Also, 8 pieces of tape were attached to the ends of the box. Longer pieces of tape were used to wrap around the head, elbow, wrist, knee, and ankle. Shorter tape was used to cover the shoulder and hip. The lifter used a box 70 cm wide × 35 cm long × 30 cm high. The mass of the box was manipulated by placing weights inside the empty box. The box had two handles, each centred on the left and right sides of the box (as viewed by the lifter).

Recording procedure

Just as in Bingham's (1993) study, the lifter was informed about the mass of the box each time before the box was lifted. Each recorded lift began with the box resting on the floor. The lifter entered the field of view from the right, stood in front of the box after taking a few steps, bent down and grasped the box handles, and then lifted the box and raised it to a natural carrying height. Then, the lifter took a few steps forward, placed the box on the table, and took one step back. Once again taking a step forward, the box was lifted from the table and was moved to the carrying position. After turning around in an anticlockwise direction and taking a couple of steps forward, the lifter put the box down at its initial resting location. The lifter then stood up, took a step over the box, and walked to the right leaving the field of view. The lifter performed five masses (2.3, 9.1, 15.9, 22.7, and 29.5 kg) three times each. The 15.9-kg mass, which served as the standard mass, was recorded three times in addition.

Design

Just as in Bingham's (1993) study, the recordings were made in three blocks of six lifts. The lifts in each block were randomized with the exception of one 15.9-kg lift, which was shown in the beginning of the block and whose actual mass was revealed. This lift was considered the standard. No video resolution was lost because the video camera that took the recording was directly connected to the projector for display without capturing the video onto the computer.

Experimental procedure

Five or six observers at a time were seated 2 to 6 m from the large screen. Instructions were given to the observers regarding the nature of the experiment and what they were going to view on the screen. Before observing the lifts, all observers received haptic information as they were allowed to actually lift a known standard mass (15.9 kg). After observing each lift, the observers estimated the weight or mass of the lifted box in writing, either in pounds or in kilograms depending on their preference. The estimation in pounds was converted to kilograms. There were a total of 18 trials, and the 1st, 7th, and 13th trials served as standard trials in which observers knew the actual mass (15.9 kg).

Results

The results are shown in Figure 1. The correlation between actual mass and estimated mass ($r = .9$), average absolute error of five mass estimations ($AE = 4.0$ kg), and standard error of mass estimations ($SE = 0.4$ kg) were quite similar to Bingham's results if not better ($r = .6$, $AE = 3.5$ kg, $SE = 0.7$ kg). Thus, Experiment 1 ascertained that we were able to replicate Bingham's results of excellent mass estimation when circumstances are perfect. We took this point-light display as the basis to systematically vary the information in Experiments 2–4.

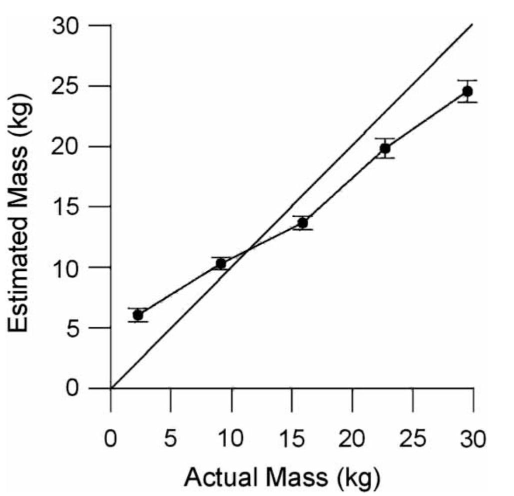

Figure 1. *Estimated mass and standard error when observing a lifter in point-light display generated by pieces of retroreflective tape in Experiment 1.*

EXPERIMENT 2: SPATIAL VARIATION

Now that we had established a standard of accurate mass judgement, we investigated the effect of reducing spatial information. A pilot study had suggested that the motion of the lifted box itself might be sufficient. The purpose of Experiment 2 was to determine whether this is in fact the case or whether the actor's motion during the lift is necessary to accurately perceive mass. In other words, is biological motion the key or is box acceleration sufficient to explain perceived mass?

Method

Participants

A total of 19 observers (7 men and 12 women, age = 21 $\pm$ 1.4 years) viewed only the box while 19 different observers (9 men and 10 women, age = 22 $\pm$ 1.5 years) viewed the whole lifter with the box.

Stimuli and apparatus

The lifter shown in point-light display in Experiment 1 was again used. To perform video editing, all 18 (3 standard and 15 regular) lifts were captured without any compression or loss of frames and were edited using digital computer graphics techniques (Commotion Pro). Each lift was edited frame by frame to occlude the whole body and show only the box. The sequence was exactly the same length as the original but the entire lifter was edited out such that only the box point-lights remained. The 18 video clips were compiled using Adobe Premiere. Each lift video clip was compressed twice, once when saved after the occlusion and another time after compilation. Therefore, we also compressed the original full-model (box + lifter) video twice to ensure that the predicted difference between box and full-model display was not due to video resolution lost from compression. The results of the full-model point-light display condition were also compared to the same full-model point-light display condition as that in Experiment 1 to ensure that the potential but unlikely effects of compression could be factored out. The procedures were the same as those in the point-light display condition in Experiment 1.

Results and discussion

The results of the full-model point-light display ($AE = 4.3$, $r = .9$, $SE = 0.7$) in Experiment 2 were commensurable with the results of the same condition in Experiment 1 ($AE = 4$, $r = .9$, $SE = 0.4$). The t test comparison of estimated mass between the display in Experiment 1 and the compressed video display in Experiment 2 showed nonsignificance, $t(1, 35) = -0.7$, $p = .388$, which indicates that video resolution was not lost during compression of video files or that the difference was unnoticed.

An independent t test showed that observers judged the mass more accurately in full-model (box + lifter) displays than in the box-only displays, $t(1, 36) = 7.5$, $p < .01$. Figure 2 clearly shows that observers' judgement was much poorer in box-only displays. Apparently the object motion by itself cannot specify the kinetic property to any precision, and the bodily movement is the key component of mass perception. Nonetheless, there was a positive correlation ($r = .52$) between actual and judged mass in box-only display.

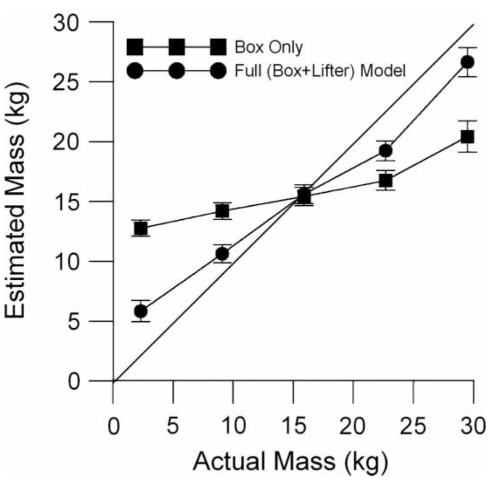

Figure 2. *Estimated mass and standard error when observing either the full model (lifter + box) or box only in Experiment 2.*

EXPERIMENT 3: TEMPORAL VARIATION

In addition to the occlusion of the actor, in Experiment 3 we played the video either fast or slow to determine whether judgements might be affected by velocity, which would be suggestive of a perceptual velocity heuristic. With the results of Experiment 2 showing a poor judgement with only object motion, we hypothesized that an observer's reliance on a velocity heuristic would be greater with limited information. To keep the number of trials manageable, we dropped the number of different masses of the box to two masses with the presence/absence of the lifter and presented all trials at five different velocities.

Method

Participants

A total of 68 observers (age = 21 $\pm$ 1.1 years) were randomly assigned to one of 4 groups (2 mass $\times$ 2 display): 9.1 kg and box only; 9.1 kg and box + lifter; 22.7 kg and box only; 22.7 kg and box + lifter.

Design and procedure

Three 9.1-kg and three 22.7-kg lifts in both box-only and full-model (box + lifter) displays from Experiment 2 were selected, and each lift was displayed in five different speeds including normal speed, two fast speeds (1.1 and 1.2 times faster than normal), and two slow speeds (0.9 and 0.8 times slower than normal). In each group, 15 trials (3 lifts of same mass $\times$ 5 speeds) were displayed. The procedures were the same as those in Experiment 1 with the exception of observers not receiving standard lift and haptic experience. A one-way analysis of variance (ANOVA) was performed on the estimated mass for each group to determine potential speed effects; and a 2 $\times$ 2 (Mass $\times$ Display) ANOVA was performed on the coefficient of variation (*CV*) to determine which group's judgement was more variable.

Results and discussion

Significant effects were found for speed in all groups: 9.1 kg and box only, $F(4, 64) = 10.99$; 9.1 kg and box + lifter, $F(4, 48) = 6.83$; 22.7 kg and box only, $F(4, 64) = 14.01$; 22.7 kg and box + lifter, $F(4, 68) = 13.21$, ps $< .01$. Also, a 2 × 2 (Mass × Display) ANOVA on *CV* showed a significant effect for display, $F(1, 65) = 4.29$, $p = .043$, but no effect for mass, $p = .103$, and no interaction, $p = .117$ (Table 1).

As shown in Figure 3, observers were swayed by the change in display speed. The general finding was that boxes were judged to be lighter the faster the trial was displayed. This finding is in line with the results of Andersson and Runeson's (2008) where the object with the fastest speed after collision was judged as lighter. For the light (9.1-kg) mass, the velocity effect was equally strong in the box-only and full (box + lifter) condition, but for the heavy (22.7-kg) mass the effect was modulated by the richness of information. An independent *t* test showed that observers significantly judged the 22.7-kg mass lighter in the box-only display than in the box + lifter display, $t(1, 33) = -2.38$, $p = .023$. The *CV* of the box + lifter group was much smaller than that of the box-only group, which indicates that observer judgement was more swayed by the velocity when information was more limited. Although there was no interaction, the difference between the two groups tended to be more noticeable for the heavier mass (22.7 kg) as shown in Table 1. After the data collection, some participants reported that they were suspicious of the video speed, and a couple of participants in the box + lifter condition were so confident of a speed manipulation that they reported the same mass for all 15 trials. The box + lifter group was more suspicious than the box-only group. Nevertheless, the observers were mostly deceived by the play speed. Even at very slight changes in speed, the observers were not sensitive enough to notice that the motion was not in real time but sensitive enough to perceive it as a heavier or a lighter mass.

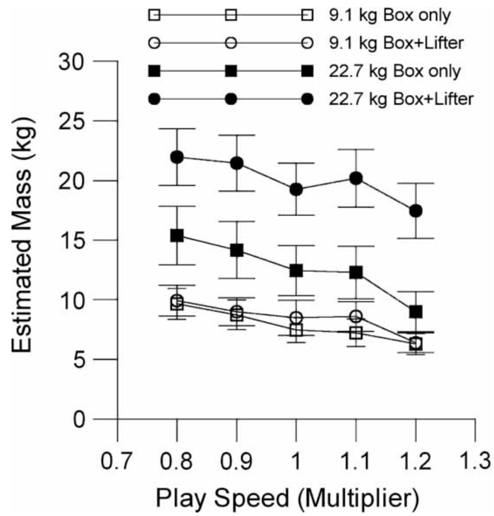

Figure 3. *Estimated mass and standard error when observing 9.1-kg and 22.7-kg mass displayed in five play speeds, either box only or box + lifter. The value of play speed is the multiplier of the normal speed at 1.*

Table 1. *Coefficient of variation of judged mass of two masses in two display conditions*

	Mass	
*Display**	*9.1 kg*	*22.7 kg*
Box	.25 (.12)	.25 (.12)
Box + lifter	.24 (.15)	.14 (.09)

Note: Between-subject standard deviation in parentheses.
*Significant effect at $p < .05$.

EXPERIMENT 4: VARIATION OF JUDGEMENT TYPE

Most of the studies on the perception of lifted mass in the past have used either verbal or written reports when judging mass. This direct parameter estimation may underestimate observers' action-based abilities to judge mass, as one might hypothesize on the basis of related tasks.

For instance, in studies on slant estimation, Proffitt and his colleagues (Bhalla & Proffitt, 1999; Creem & Proffitt, 1998; Proffitt, Bhalla, Gossweiler, & Midgett, 1995) have shown that observers overestimate slant when assessed by verbal reports, but less so or not at all with an action-based measure. An underlying dissociation of the two visual systems—the ventral stream for perception and dorsal stream for action (Milner & Goodale, 1995)—might be at work in mass estimation as well. The ventral stream projects to the inferotemporal cortex and is responsible for the perception of an object's identity. The dorsal stream projects to the posterior parietal cortex and is responsible for spatial localization and visually guided actions. The idea of two visual processing pathways has its roots in a proposal made by Schneider (1969) and has not remained uncontested (e.g., Franz, Gegenfurtner, Bülthoff, & Fahle, 2000). The idea also calls for an investigation of a potential difference between a merely visual versus an action-based judgement of mass. The purpose of Experiment 4 was to determine whether perception of kinetic properties with action involvement is different from mere observation. We believe that observers mainly have access to cognitive knowledge when using pencil-and-paper or verbal report. Hence, we hypothesized that observers' estimation of mass with action is different from uninvolved perception. Estimates given by reproducing a force that matches the felt weight were chosen as an additional dependent measure.

Method

Participants

A total of 20 participants (9 males and 11 females, age = 21 ± 1.3 years) estimated the mass both verbally and in action after observing the lifts used in Experiment 1 with the order counterbalanced. They also produced an action that would match the mass verbally given by the experimenter.

Design and procedure

The participants came into the laboratory for three sessions. In the first two sessions, the participants observed the same lifts as those used in Experiment 1 with the exception of observing the lifts on a smaller computer monitor one person at a time. Also, the haptic experience and standard mass lift were not given to avoid the different effects they may have on the action system. The participants judged the mass by verbally reporting the mass to the experimenter or by pulling on a pair of handles placed in front of the participant identical to the handles that were attached to the box used in Experiment 1. The participants were asked to imagine that the handles in front of them were the handles on the box they had just seen on the computer monitor. After observing the lift performance from the point-light model, the participant was asked to pull on the handles as if to lift the box just off the ground. They were strongly encouraged not to pull more than necessary but just enough to get the "box" off the ground. The handles were connected to load cells that measured tension. The maximum summation of force from both load cells was considered the participant's estimated mass. To acquire independent information on the use of the loaded handles, during the third session participants were asked to pull on the handles to match a mass merely given verbally. The experimenter verbally indicated the masses that nominally matched the participant's previous judgements. The order of the first two sessions (verbal and action) was counterbalanced while the third session (verbal-action) came last.

The verbally given masses by the experimenter matched the verbal report that the participant had given in the previous session. The purpose of testing the known masses was to determine any internal consistency that may exist between the perception and action systems. In other words, a participant may observe a lift and verbally report 10 kg but pull 20 kg. However, this difference may nonetheless be the result of internal consistency where the mass is perceived the same way for both verbal report and action, but where it is scaled differently. To test for internal consistency, the participants were asked to pull and match a verbally given mass that they had reported in a previous session.

Results and discussion

In a 3 × 5 (Response Type × Mass) repeated measures ANOVA of mass estimation, there were significant effects for response type, $F(2, 38) = 55.5$; mass, $F(4, 76) = 84.7$; and interaction, $F(8, 152) = 6.9$, $ps < .01$. The post hoc (Bonferroni) analysis of response type showed that observers' verbal mass estimation was significantly smaller than that in the action and verbal-action response. Also, all five masses were significantly different from each other, $ps < .05$ (Figure 4). Action responses were much greater than the verbal responses but were not different from verbal-action responses, which indicates a high internal consistency. For instance, on a typical trial a lift was judged to be 13.7 kg in the verbal and 44.6 kg in the action condition, but when asked verbally to pull 13.7 kg, this observer pulled 45.4 kg. This high internal consistency shows connectedness of the perception and action systems and perhaps the guidance of action by the perception system rather than the two being separate and independent entities.

The results clearly indicate that the verbal estimations were in the right ball park whereas observers vastly overestimated the force they needed to produce and lift a given weight. At the least, this indicates that the action and perception systems are differently calibrated.

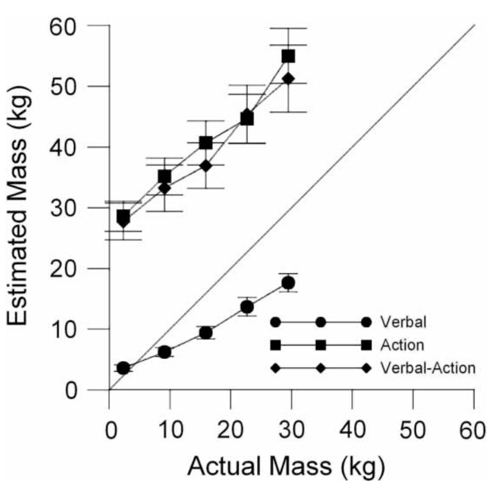

Figure 4. *Estimated mass and standard error when using verbal report, action, or haptic experience in Experiment 4.*

EXPERIMENT 5: VARYING LIFTER STRENGTH

Bingham (1993) initially showed that observers can identify lifter size whereas later Shim et al. (2004) showed that observers had difficulty judging mass when lifters of different size performed. However, the displays in Shim et al.'s study differed on several dimensions from Bingham's (1993) displays: The masses were much heavier than those in Bingham's displays, and the display only contained lifting the box off the ground to a carrying position—the walk-up to the box was omitted. Also the observers were not given a standard mass, and thus conditions may have been less favourable for finding good performance. We readdressed the issue of whether observers can identify lifter strength when the context situation is more ideal.

For a wide range of masses, a person may adopt his or her efficient way of lifting and carrying. Rather than using specific lifting patterns for individual masses, a lifter may use a particular pattern for a group of masses to achieve lifting efficiency. However, when the mass exceeds a certain level of difficulty, a different lifting pattern may emerge and be adopted to maintain efficiency. Previous kinematic analysis of lifting motions (Shim & Carlton, 1997) has shown that some maximum values of kinematic parameters were not linearly related to actual masses. Rather, the kinematic values seemed to correlate higher with estimated masses. However, the range of masses lifted was small. In Experiment 5, we increased the range of masses from near zero to near 100% of lifter's strength to further examine the relationship between actual and estimated mass. We hypothesized that mass judgement will be similar among light masses and become more variable as the mass gets heavier at the turning point when lifters adopt a different lifting strategy. However, as the mass continues to increase towards the maximum capacity, the judgement should continue to plateau as the lifting strategy will remain unchanged.

Method

Participants and model lifters

A total of 15 observers (6 males and 9 females, age = 21 ± 1.6 years) viewed recordings of a normal (height = 1.7 m, mass = 58 kg) model lifter, and 14 observers (6 males and 8 females, age = 22 ± 1.8 years) viewed recordings of a strong (height = 1.8 m, mass = 141 kg) model lifter. The strong model was taller and more than two times heavier than the normal model who was a gymnast.

Procedure

We used circular (1.5 cm in diameter) reflective markers instead of reflective tape for a slight possibility that observers might pick up lifter size through contour information given by patches of tape that surround the elbow, wrist, knee, and ankle.

We first determined the maximum mass that our two model actors could lift and carry and divided the maximum into nine masses starting from 2.3 kg. We recorded nine lifts ranging from 2.3 kg to 38.6 kg with increments of 4.55 kg for the normal lifter and nine lifts ranging from 2.3 kg to 75 kg with increments of 9 kg for the strong lifter. These nine lifts per model were recorded in three nonconsecutive days with the lifts randomly ordered in each day. Therefore, a total of 27 lifts were recorded for each model and were shown to observers. The other procedures were the same as those in Experiment 1. Thus, the observers in both groups verbally judged all recorded lifts by the respective model.

Results and discussion

Figure 5 shows the estimated mass of the nine lifts each performed by the strong and normal lifters with masses ranging from 3% to 100%. For the strong lifter, the estimated mass steadily increased with increase in mass. However, for the normal lifter, the estimation curve of heavier masses had a much greater slope than the estimation curve of lighter masses.

After estimating the masses, the observers were asked to estimate the lifter profile regarding age, height, body mass, gender, and strength. The group that observed the strong lifter underestimated his body mass by 66.1 kg while the group that observed the normal lifter overestimated by 24.8 kg. Surprisingly, the observers even estimated the normal lifter to be somewhat heavier than the strong lifter, $t(1, 26) = -2.13$, $p = .042$, maybe because the strong lifter was well trained and might have produced quicker lifts although the average weights were a lot heavier than those of the normal lifter. Similar results also include the fact that 71% of observers thought the strong lifter was strong, while 93% thought the normal lifter was strong, respectively (Table 2).

The strong lifter's arm swing during walking was quite limited due to the size of his trunk. Nonetheless, the observers did not pick up on this information. Instead, the observers thought the strong lifter was lighter and the normal lifter heavier because the strong lifter struggled much less to lift the maximum mass while the normal lifter appeared to put more effort in getting the box off the ground and into the carrying position.

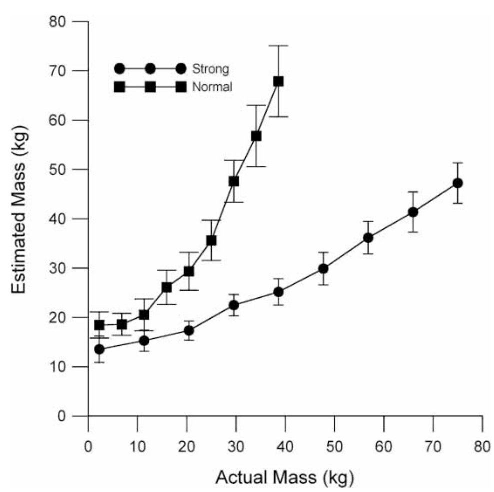

Figure 5. *Estimated mass and standard error when observing a strong and a normal strength lifter with actual masses ranging from almost 0% to 100% of their maximum lifting capacity.*

Table 2. *Actual and predicted lifter profile in the strong and normal lifter observing groups*

		Lifter profile			
Group		*Age (years)*	*Height (m)*	*Mass (kg)*	*Gender/strength*
Strong	Actual	22	1.8	141	Male/strong
	Predicted	24.8 (4.2)	1.77 (0.10)	74.9* (11)	71% M/21% S
Normal	Actual	21	1.7	58	Male/normal
	Predicted	23 (3.8)	1.83 (0.11)	82.8* (8.4)	93% M/43% S

Note: Between-subject standard deviation in parentheses. M = male. S = strong.
*Significant effect at $p < .05$.

It is possible that the 75-kg box was even below what the strong lifter could pick up and carry, but we steadily increased the mass and stopped when the lifter subjectively felt he could no longer pick up and carry the mass.

We did not prescribe a particular lifting technique and instead allowed the models to lift as freely and efficiently as they could without a constraint. We did not notice a change in the technique, and both have used the leg lift technique. Observers' judgements seemed to match more closely to the box mass/body mass ratio. For example, the 29.5-kg box for the normal lifter had the same ratio as the 75-kg box for the strong lifter. Where the ratios were same in these two conditions, judgements were also the same. Nonetheless, the fact that observers were unaware of the lifter's size, mass, and strength seems to indicate that observers were attuned to the lifter's effort rather than to the true mass.

GENERAL DISCUSSION

When judging mass on the basis of point-light displays, observers can be remarkably accurate. The question whether such performance reflects a universal ability to exploit the relevant kinematic information or whether good performance breaks down with contextual changes was at the focus of our experiments. The latter was the case. The more reliable the context, the fewer parameters needed to be factored into a successful judgement. When conditions are right, observers can derive mass judgements from viewing the kinematics of the box and the lifter's body. However, this ability breaks down as soon as the context—for instance, the speed of the entire lift and information leading up to the lift—is varied. Systematic context variations, in particular that of lifter strength and richness of the display, have produced large variations in judgement performance, suggesting that observers rely on fairly simple strategies, such as a velocity heuristic to the effect that fast object motion is associated with light masses.

Unfortunately, the story is not as clear cut. The velocity heuristic was modulated, to some degree, by more sophisticated information contained in the lifter's kinematics. Observers' estimation was less influenced by the changes of the lifting speed when they observed the lifter in full. The mass estimation error was also less in the full display than in the box display. Kinematic information about the lifter itself seems to be crucial, indicating that judgement performance cannot be reduced to a simple velocity heuristic but that velocities of the actor's joints must be compared to velocities of the lifted object.

Our results are not necessarily in conflict with Runeson and Frykholm's (1983) analysis of the kinematic properties that might enable observers to judge lifted mass. Rather, the results reveal that the perceptual process is more adaptive than previously thought. Runeson and Frykholm already manipulated the speed of the lifted box but implemented it by deceptively lifting a light mass very slowly, without being able to control the resulting overall kinematic gestalt. Runeson and Frykholm suggested that the kinematic properties originating from the constraints of maintaining balance provide accurate estimation of mass despite the lifter's deceptive attempts.

Our conclusion of adaptive perceptual processes is further strengthened by the account that observers can, when the conditions are right, extract object mass from complex movement patterns. However, in doing so they seem to exploit a general tendency that the heavier the object to be lifted, thrown, or handled, the smaller the peak velocity of the effector (see Bingham, 1993; Shim & Carlton, 1997).

In our Experiment 2, observers were clearly affected by the removal of lifter kinematics. When only the object in motion was displayed faster objects were judged to be lighter than slower ones. However, biological motion of the lifter appeared to be particularly informative above and beyond object motion. In Experiment 3, when speed was manipulated by speeding up or slowing down the biological motion observers misjudged mass as a function of speed according to the rule that fast is light. Interestingly, observers' perception was sensitive enough to detect the change in speed, yet with few exceptions they were unaware that the motion was unnatural or manipulated. Thus, observers seem to have variable strategies in their repertoire partially based on a simple velocity heuristic and partially accessing more sophisticated information about kinetics.

Verbal mass judgements differed vastly from action-based force measures indicating that, in quantitative terms, verbal estimates cannot be trusted. Despite the verbal underestimation, high internal consistency between verbal and action measures leads us to believe that the same mass is nonetheless perceived. For example, as shown in Figure 4, observers verbally reported 14 kg but pulled 45 kg in the respective action when they saw a 23-kg lift. However, when they were asked to just pull 14 kg without viewing the lift, they also pulled 45 kg. It seems that the verbal scale underestimates whereas the action scale overestimates force. Using a wider range of mass and lifters of different strengths in Experiment 5 confirms this interpretation that perception of kinetic properties was accurate in ordinal terms but inaccurate with respect to true magnitude. The results also show that knowledge or correct assumptions about the context (in this case lifter strength) are crucial for the ability to judge mass on the basis of kinematics.

Original manuscript received 27 August 2008
Accepted revision received 23 December 2008
First published online 17 April 2009

REFERENCES

Andersson, I. E. K., & Runeson, S. (2008). Realism of confidence, modes of apprehension, and variable-use in visual discrimination of relative mass. *Ecological Psychology*, *20*, 1–31.

Barclay, C. D., Cutting, J. E., & Kozlowski, L. T. (1978). Temporal and spatial factors in gait perception that influence gender recognition. *Perception & Psychophysics*, *23*, 145–152.

Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1076–1096.

Bingham, G. P. (1987). Kinematic form and scaling: Further investigations and the visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance*, *13*, 155–177.

Bingham, G. P. (1993). Scaling judgments of lifted weight: Lifter size and the role of the standard. *Ecological Psychology*, *5*, 31–64.

Creem, S. H., & Proffitt, D. R. (1998). Two memories for geographical slant: Separation and interdependence of action and awareness. *Psychonomic Bulletin & Review*, *5*, 22–36.

Cutting, J. E. (1978). Generation of synthetic male and female walkers through manipulation of a biomechanical invariant. *Perception*, *7*, 393–405.

Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society*, *9*, 353–356.

Franz, V. H., Gegenfurtner, K. R., Bülthoff, H. H., & Fahle, M. (2000). Grasping visual illusions: No evidence for a dissociation between perception and action. *Psychological Science*, *11*, 20–25.

Gilden, D. L., & Proffitt, D. R. (1989). Understanding collision dynamics. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 372–383.

Gilden, D. L., & Proffitt, D. R. (1994). Heuristic judgment of mass ratio in two-body collisions. *Perception & Psychophysics*, *56*, 708–720.

Hecht, H. (1996). Heuristics and invariants in dynamic event perception: Immunized concepts or nonstatements? *Psychonomic Bulletin & Review*, *3*, 61–70.

Johansson, G. (1950). *Configurations in event perception.* Uppsala, Sweden: Almqvist & Wiksell.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics*, *14*, 201–211.

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception & Psychophysics*, *21*, 575–580.

Marey, E. J. (1972). *Movement.* New York: Arno Press. (Original work published 1895.)

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action.* Oxford, UK: Oxford University Press.

Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin & Review*, *2*, 409–428.

Proffitt, D. R., & Gilden, D. L. (1989). Understanding natural dynamics. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 384–393.

Runeson, S. (1995). Support for the cue-heuristic model is based on suboptimal observer performance: Response to Gilden and Proffitt (1994). *Perception & Psychophysics*, *57*, 1262–1273.

Runeson, S., & Frykholm, G. (1981). Visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 733–740.

Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as informational basis for person and action perception: Expectations, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General*, *112*, 585–615.

Runeson, S., & Vedeler, D. (1993). The indispensability of precollision kinematics in the visual perception of relative mass. *Perception & Psychophysics*, *53*, 617–632.

Schneider, G. E. (1969). Two visual systems. *Science*, 895–902.

Shim, J., & Carlton, L. G. (1997). Perception of kinematic characteristics in the motion of lifted weight. *Journal of Motor Behavior*, *29*, 131–146.

Shim, J., Carlton, L. G., & Kim, J. (2004). Estimation of lifted weight and produced effort through perception of point-light display. *Perception*, *33*, 277–291.

Todd, J. T. (1983). Perception of gait. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 31–42.