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Visual Perception of Lifted Weight From Kinematic and Static (Photographic) Displays

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Observers of patch-light videotape displays can reliably discriminate levels of lifted weight; accuracy of judgments sometimes approximates that achieved when the observers themselves lift weighted boxes. Results of 6 studies reveal impressive levels of visual weight discrimination based on static displays (photographs) of certain action phases sampled from videos of entire lifting-carrying events. Slow and controlled actions (e.g., walking, placing box on table) supported optimum weight discrimination for both photographic and video displays, whereas the action of lifting a box yielded high levels of discrimination only for video displays. Static and kinematic specification of dynamics, as well as the work by painters and photographers to depict humans and other animals in action, is discussed.

Numerous investigations have shown that the visual perception of events involving living creatures can be supported by purely kinematic (i.e., movement) patterns. Heider and Simmel (1944) and Michotte (1963) were among the first to demonstrate experimentally that vivid impressions of animacy can be obtained easily by kinematic patterns of simple geometric forms. Variants of Johansson's (1973) "point-light displays"—films of actors performing in darkness and visible only by small lights attached to their major joints—have been used successfully in many programs of research to show that observers, using only kinematic structure in the absence of static (configural) form, can reliably detect properties of persons in action, such as their gender (Kozlowski & Cutting, 1977), identity (Cutting & Kozlowski, 1977), the amount of weight being lifted (Bingham, 1987b, 1993; Runeson & Frykholm, 1981, 1983), and emotional expressions (Bassilli, 1978). These studies, along with others on the visual perception of inanimate events (e.g., Bingham, 1987a, 1995; Bingham, Rosenblum, & Schmidt, 1995; Runeson, 1977/1983; Runeson & Vedeler, 1993), have provided strong support for the principle of *kinematic specification of dynamics,* which maintains that "as soon as a minimum degree of complexity is exceeded, the kinematic patterns of events contain information about relevant dynamic properties" (Runeson & Frykholm, 1981, p. 733). Such properties would include the weight of objects being manipulated, the effort necessary for an action, and, more broadly, "the intentions, expectations, moods, and abilities" of a person that may influence the course of an event (Runeson & Frykholm, 1981, p. 733). *Perception of dynamic properties is probably more relevant to adaptive animal action than is the perception of simple variables of displacement, velocity, and acceleration* (see also Gibson, 1979/1986).

The success of experiments showing that kinematics alone can specify the dynamics of human action has led some researchers to accept, tacitly or explicitly, that static configurations of the human form are normally not informative about event dynamics, or, even if they are, that their importance is less than that of dynamic factors. These static structures would include postures in the absence of movement, facial expressions held in time, visible patterns of muscular contraction, or beads of perspiration. In the domain of the psychology of art, however, Arnheim (1954/1974, 1988) has maintained for decades that static visual displays, as well as moving images, convey dynamics—"the very basis of expression" (Arnheim, 1988, p. 585), and numerous authors have examined the ubiquity of "movement" in certain static images (e.g., see Ward, 1979, for a concise review). Nonetheless, to our knowledge, there are no experiments that have compared directly the relative informativeness of static versus kinematic displays of human activity. For example, Runeson (1977/1983, p. 14), explicitly stressing kinematic over static structures in the

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visual perception of dynamic events, stated that the shape and color of objects, for example, would at best provide limited information about the stable properties of objects. He then delivered a well-supported argument that "kinematics should contain rich information about what a person is doing" (Runeson, 1977/1983, p. 25), basing this view on established principles of mechanics and biomechanics that enforce a specificity of movement patterns to the dynamic factors, internal and external, that produce them.

In a subsequent article on the visual perception of weights that were lifted by another person, Runeson and Frykholm (1981) did consider whether "facial expressions or muscle strains would be more informative than the kinematic pattern" (p. 733) but then rejected this possibility on the basis of the work of Johansson (1973), Kozlowski and Cutting (1977), and others. These studies using the patch-light technique (i.e., a simple variant of the point-light technique based on high-reflectance patches rather than lights) show relatively high judgment accuracy for observers viewing only the kinematic patterns of human activity. In Runeson and Frykholm's (1981) own studies on the visual perception of lifted weight, observers of live actors frequently mentioned facial expressions, muscular strains, and sounds from the actor or box when asked to explain the basis of their judgments, but weight discrimination in the kinematic-only (patch-light) display condition (Experiment 1) showed a relatively small performance decrement when compared with both a condition in which observers watched as an actor lifted in plain view and a condition in which the observers themselves lifted the weights (Experiment 2). In summarizing their results, Runeson and Frykholm reasoned that backward lean probably is not a source of information because, among other reasons, its value should depend critically on how actors choose to walk and distribute weight across their feet. These studies again demonstrated that kinematic displays can be highly informative about the dynamics of an event, but they leave open the question of the existence of configural (static) structure that may provide a firm informational support for the perception of dynamics. One unintended effect of their presentation may have been to leave some readers with the notion that static structures are normally not reliably informative about the dynamic conditions under which they emerged.

Runeson himself has never sought to discount the general importance of static structures in perception. As Runeson and Lind (1981) observed, "Our visual system functions quite well without motion and . . . static information is not automatically subordinate to information from motion. A complete theory of vision will therefore have to deal with both types of information and how they are conjoined" (p. 281). There has been a temptation, however, for Gibsonians, in their rejection of traditional, "image-based" theories of vision, to overexaggerate the impoverishment of static structures. This was true of Gibson himself (e.g., Gibson, 1966b, 1979/1986). His occasional, apparently unqualified denials of the informativeness of static structures were never easy to reconcile with the facts of pictorial representation, nor with his own attempts to explain how pictures work (see Costall, 1993, 1996).

There can be no question that kinematic structures are more than adequate when presented as the sole bases of event perception in these experimental studies. Might not the natural visual array, when frozen at a particular instant as a static image, also prove rich enough in structure to preserve dynamic properties? It probably is true that a large set of static structures (e.g., posture, facial expressions, muscular strain) covary with kinematic structures in human activity, and it is conceivable that some of these static structures may specify dynamics. The specification power of static structure is an empirical question worthy of serious scientific attention.

The question is more than academic; it is both a practical and artistic concern. Capturing and expressing dynamic qualities is a problem routinely faced, and overcome with varying degrees of success, by painters, photographers, and sculptors of the human and other animal forms, when their purpose is to portray movement, effort, emotion, intention, and capacity for action. In the late 19th century, painters were astonished by the instantaneous photographs of horses in full gallop, which hardly convey forward movement at the moment when all four legs are off the ground and, as it happens, jackknifed inward. These photographs sharply contrasted with traditional European depictions, such as the expressive yet "factually" incorrect so-called flying-gallop position—forward and rear legs outstretched (Scharf, 1968/1974). Muybridge (1899/1957, 1901/1955), generally regarded as the first photographer to bring the new instantaneous photographs of animal motion to the attention of artists and scientists, was well aware of the representational dilemma posed by these frozen images: Photographs of rapid motion faithfully record an instant yet may create "an impression so vague as to be dispelled by the first studied observation" (Muybridge, quoted in Scharf, 1968/1974, p. 217). Although some artists of the day rejected outright these instantaneous images of movement, others, such as Eakins and Degas, embraced the photograph—always in the service of intellect—as a tool of memory or as a probe of movement. "Though his drawings are based on the correct positions of the canter or gallop" wrote Scharf of Degas's studies of horses, "they only indicate movement and do not make it apparent which movement it is. They provide perhaps a clue to the subtle working of his mind in extracting a formal imagery from instantaneous photographs" (Scharf, 1968/1974, p. 208). Some artists of the late 19th century were therefore stimulated by the photograph to reconsider the expression of dynamics in static images, and some of their paintings can be regarded as experiments in the representation of movement.

Merleau-Ponty (1945/1962, 1961/1964) discussed the common failure of literal, photographic representations of movement as compared with paintings that result from a disciplined blending of glimpses:

> The painting itself would offer to my eyes almost the same thing offered them by real movements: a series of appropriately mixed, instantaneous glimpses along with, if a living thing is involved, attitudes unstably suspended between a before and an after—in short, the outsides of a change of place which the spectator would read from the imprint it leaves.

> Here Rodin's well-known remark reveals its full weight: the instantaneous glimpses, the unstable attitudes, petrify the movement, as is shown by so many photographs in which an athlete-in-motion is forever frozen. We could not thaw him out by multiplying the glimpses. Marey's photographs, the cubists' analyses, Duchamp's *La Mariee*, do not move; they give a Zenonian reverie on movement. We see a rigid body as if it were a piece of armor going through its motions; it is here and it is there, magically, but it does not *go* from here to there. (Merleau-Ponty, 1961/1964, pp. 184–185)

Examples of a simple yet effective blending of glimpses and attitudes can be seen in the illustrations of horses in American frontier life by Frederic Remington, many of which conform closely (but not exactly) to photographic images by Laton Alton Huffman and by Eadweard Muybridge (Jussim, 1983; Ward, 1979). After Muybridge's photographs of animal locomotion were first published in 1887, Remington's more literal and controversial depictions of galloping horses often show modifications of the forward limbs relative to the rear to yield, it seems, more reach and forward momentum.

Merleau-Ponty's (1961/1964) remarks on painting and photography underscore two distinct issues, both relevant to science and art. First, are there "contrived" informative structures, intentionally or unintentionally deployed, that are peculiar to static depictions of an event? This issue has been addressed directly in several recent empirical investigations, including those of Carello, Rosenblum, and colleagues on the use of pictorial devices in handmade drawings (Carello & Kinsella-Shaw, 1988, 1991; Carello, Rosenblum, & Grosofsky, 1986) and photographs of "streak lines" produced by actors, who were wearing point lights, while they moved in front of a camera on long exposure (Rosenblum, Saldaña, & Carello, 1993). Using hand-drawn pictures, Carello and Kinsella-Shaw (1988), for example, found that the drawing devices that were most successful in depicting the lifting of a heavy versus a light box reflected the dynamics of the event directly (e.g., sweat, backward lean); the size of the box, which on average will correlate positively with weight, was an important predictor only for weight judgments for the younger children in their developmental study. Carello and Kinsella-Shaw argued, following Gibson (1966a, 1971, 1979/1986), that pictorial devices create their own optic array when explored by an observer and that the optical properties of pictures—their "geometric field"—need not duplicate those of a naturally occurring array to capture the same information. Similarly, Rosenblum et al. (1993) argued that the addition of natural (not drawn) streak lines to photographs of moving actors does not simply provide a cue to be interpreted via the application of conventional picture-interpretation rules. Rather, streak lines provide a visible geometric object—the path of movement—that enhances the perception of movement because the geometrical object is specific to the dynamics and kinematics that created it. Notice, however, that these studies of static displays typically add a geometric structure to static drawings and photographic images to support movement perception, a structure that would either be unavailable or not normally visible within a natural optic array.

Therefore, the existing research does not address directly a more basic issue raised by Merleau-Ponty's (1961/1964) comments on the limitations of photography. Must the photograph inevitably "freeze" movement? Are there no reliable informative relations between static (configural) structures and human event dynamics in the natural visual array that could be re-presented in a static photograph? Freyd's (1983) work on "representational momentum" in picture perception is highly suggestive: Under some conditions of viewing, static images of objects in motion are remembered as being carried forward along the motion path. Shiffrar and Freyd (1990, 1993) found, for example, that some tachistoscopically presented alternating pairs of photographs of the human body in different positions yielded biologically appropriate apparent motion paths, not necessarily the most direct paths. As far as we know, however, no study on the static depiction of human dynamics has isolated naturally occurring configural structures, such as postures in lifting and carrying, in a test of visual discrimination.

The current six experiments were designed to clarify two issues, often confounded, in the perception of events: (a) the extent to which observers perceive the dynamics (i.e., masses, impulse, power, or pressure) of events and (b) whether such perception depends exclusively on kinematic as opposed to static structure.[1] Michotte, in his pioneering work on event perception, appears to have been alert to this distinction; he considered examples in which the dynamic "history" of an object might in some sense be perceived (as in a cracked vase or an eroded stone), even though the dynamic process itself is not visible (e.g., Michotte & Thinès, 1963/1991, p. 66). To this end, extended videotape (kinematic), brief videotape, and photographic (static) displays of actors lifting boxes were judged by naive observers, who were asked to provide judgments of weight. Because our aim was to discover the internal logic of static depictions made from momentary samples of the naturally occurring visual array, we chose not to add structures, such as streak lines (cf. Rosenblum et al., 1993), to our displays. We hoped that the use of normal instantaneous photographs would provide some insight into the unique expressive qualities of a still image of the human in action.

Experiment 1

The purpose of Experiment 1 was to replicate the essential findings of previous studies on the perception of lifted weight (cf. Runeson & Frykholm, 1981, Experiment 2) with full video (not point-light) stimulus tapes and to provide one type of comparison for data from static presentations of photographs from the same action of lifting and carrying weights. As in previous studies, a broad range of box weights was used (1–31 kg) in five steps. Four actors were used to assess variability in observer performance due to individual differences in actor styles of lifting and carrying

[1] Contrary to current practice, we restrict the term *dynamic* to the question of masses and the impulses that move them (i.e., "forces" in everyday language), and we use the term *kinematic* (rather than *dynamic*) for nonstatic displays.

and to permit the selection of the best two actors (i.e., those whose actions were most discriminable) for the final studies on judgments of static photographs and brief videotape displays. Note that the heaviest box was close to the limit of safe and comfortable lifting over repeated trials. To minimize the risk of injury, we used only male actors in good physical health.

Method

Design. The primary independent variable was weight of the box: 1, 8, 16, 25, and 31 kg. The other variables included actor (4), observer (13), and repetition of the lifting and carrying event (3). The major dependent variable was the observer's judgment of the weight of the box in pounds, the scale of weight measurement most familiar to students in the United Kingdom.

Actors. Four men (AW, MH, SV, and AC), aged 22–46 years, were videotaped over 30 trials of lifting boxes of varying weights. All actors were in good health and moderately skilled in general fitness activities. Their own weights ranged from 49.9 to 79.4 kg, with heights ranging from 163 to 180 cm. These actors were either staff or students in a department of psychology and included the two of us.

Apparatus. A Panasonic videocamera using ¼-in. (0.635 cm) S-VHS tape (Phase Alternating Line video format signal, 25 full frames per second with a maximum of 400 lines of horizontal resolution) recorded the actions at a right angle to the direction of movement from a distance of approximately 10 m and captured the full height of each actor and approximately 3 m from left to right. A table, 73 cm high, was placed to the left of the scene and provided a surface onto which the lifted box was placed and removed during each trial; only 38 cm of the table surface was visible at the left edge of the videotaped scene. A covered, opaque plastic storage box (21 cm high × 35 cm wide × 42 cm long) was placed on the ground in the center of the scene and was filled with bricks and metal bars on each trial to yield the experimental range of weights: 1.3, 7.7, 15.9, 24.5, and 30.8 kg. The maximum weight for Actors AC, AW, SV, and MH, expressed as a percentage of body mass, was 62%, 41%, 41%, and 39%, respectively. In the remainder of this article, we use the approximate whole number values to identify the five weight values: 1, 8, 16, 25, and 31 kg. Two 300-W lights were placed to the right and left of the area of action, and a black curtain provided a backdrop for the entire scene. All actors were dressed in ordinary clothing; one of the four actors wore a short-sleeve shirt, and all wore long trousers. An S-VHS editing deck was used to produce the final experimental tapes, which were ultimately copied onto standard VHS format for playback on a 27-in. (68.58 cm) color monitor.

Recording procedure. Each recorded act began with the actor off-screen to the right, and the box placed in the middle of the scene and about 1 m from the right edge of the table. The actor entered from the right, lifted the box by its side handles, and raised it to a natural carrying height. The actor then took two to three steps toward the table, placed the box on the table, and put his hands on his sides. After waiting 2–3 s, the actor reversed the act (i.e., he lifted the box, stepped backward two to three steps, placed the box on the ground, and walked backward and out of the scene). The entire act usually lasted about 12–15 s. All actors were instructed to use the standard back protection procedure of bending their knees and keeping their back straight. Nonetheless, one actor (MH), the heaviest (79.4 kg) and perhaps the strongest, showed considerable bending of the back on most lifts. The recordings were made in blocks of five trials with the same weight, followed by a rest period of 1–5 min before the next block of trials was recorded. A total of six blocks of recorded acts were made, one for each of the five weights plus an additional 16-kg block at the end to provide an extra pool of 16-kg standard weights. The actors always knew which weight they were about to lift. Half of the actors' blocks were arranged in an ascending series of weight followed by the 16-kg standard block, with the other half of actors receiving a descending series of weight followed by the standard weight. The resulting master tape contained 30 lifts for each of four actors. Each actor's 30 lifts were accomplished in a span of about 20–30 min.

Editing. Two experimental tapes were prepared, with each presenting a series of the lifting and carrying events by two of the four actors. On each tape, three blocks of six events appeared for one actor, followed by three blocks of six events for the second actor. Each block contained examples of the actor lifting and carrying each of the five weights in random order, plus the standard 16-kg weight. The repetitions of the weight levels within actors were drawn from the third, fourth, and fifth trials within recorded blocks of events on the master tape; these later trials were chosen to yield maximally stereotypic actions. To minimize the impression that there was a limited set of alternative weights, we presented the standard first and thereafter unsystematically every five to seven trials within the three blocks for each of the two actors. The standard 16-kg acts were drawn randomly from the total pool of 16-kg acts. Therefore, the original order of events was totally disrupted on the experimental tape. Each event on the stimulus tape lasted 12–15 s and was preceded by a 6-s blank screen with the trial number in the lower right corner. Preceding the trials on which the standard weight was presented, the words "Standard–35 pounds" were displayed in the center of the blank screen.

Observers. Thirteen staff and students of a British psychology department, aged 18–65 years, served as observers of the experimental videotape and judged the weight of the box on each recorded event.

Experimental procedure. Six observers viewed one of two experimental tapes, each of which depicted two of the four actors in 18 acts of lifting and carrying (15 experimental events and 3 standard events). The remaining 7 observers viewed the second experimental tape depicting the remaining two actors, each in 18 acts of lifting and carrying. All observers were seated, up to 3 at a time, 2 m in front of the monitor in a normally lit room. The task was explained to them, and they were asked not to communicate with each other during the session. Observers were given a pencil and a response form on which to record their weight judgments (in pounds). The experimental videotapes always were displayed without sound.[2]

Results and Discussion

As in previous studies using patch-light displays (Runeson & Frykholm, 1981, 1983), the current study demonstrated an impressive ability to discriminate the five weight levels when viewing the full video displays of the four live

[2] In addition, observers provided confidence judgments (1 = low, 4 = high) for each of their weight judgments in the current procedure, Experiment 1, and in Experiments 3 and 4. Subsequent analyses revealed little variance and no interpretable pattern between confidence judgments and actual performance in all of these experiments. Hence, further analyses using this measure are not reported.

actors. Figure 1 displays the mean weight judgments as a function of physical weight and actor. The mean Pearson product–moment correlations of perceived with physical weight, pooled across observers for each actor, indicated reliable tracking of weight increments: .74 (MH), .87 (SV), .89 (AW), and .94 (AC).[3] Averaged across observers and actors the Pearson product–moment squared equaled .74, a value close to the percentage of variance accounted for in the analysis of variance (ANOVA) by Runeson and Frykholm in 1981 (68%; Experiment 1) and substantially higher than the value reported by Bingham in 1993 (56%; Experiment 1) using patch-light displays.

In addition to correlations and mean judgment values, the standard deviation of weight judgments provided another measure of performance, the level of unsystematic errors. The within-cells standard deviations, obtained by pooling within-cells variances over observers (Hays, 1988), showed generally low-to-moderate dispersion across the combinations of weight levels and actors, ranging from 1.91 (AC; 31-kg box) to 6.67 (MH; 16-kg box), with a mean of 3.70 kg. Across weight levels, dispersion did not vary greatly, ranging from 2.93 (31 kg) to 4.45 (16 kg). The values pooled across weights for each actor were 2.81 (AC), 3.15 (SV), 3.72 (AW), and 5.44 (MH) and were comparable to those reported in Runeson and Frykholm's (1981) patch-light displays of two actors (3.38 and 4.08) and live observations of actors (1.98 and 3.13). Judgments of Actor MH within each weight level yielded the most error variance. Informal comments by observers centered on the extreme bending of this actor's back while lifting all weights. This style of lifting appears responsible for the relatively high dispersion of judgments (mean $r = .74$) as well as the diminished mean slope (0.45) of the linear regression function for this actor across observers.

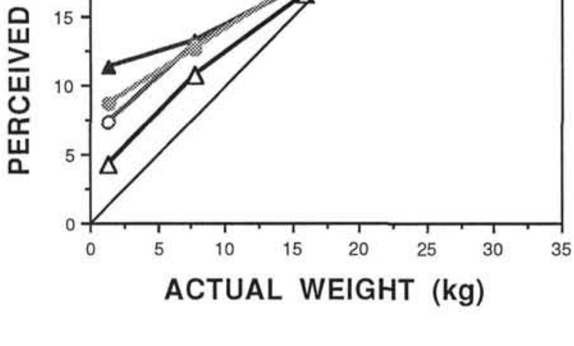

Figure 1. Perceived weight as a function of actual weight for each of four actors (AW, MH, SV, and AC) in Experiment 1.

The high values of the correlation, indicating reliable tracking of the weight levels, contrasted with the relatively low level of absolute accuracy, reflected in the low slope of the regression function. Across all actors, the mean slope of the function was .59, compared with a value .75 for the male actor of the Runeson and Frykholm (1981) patch-light experiment and with a value of .59 for the "display with standard" condition in Bingham's (1993) patch-light experiment. Figure 1 graphically displays these quantitative errors as overestimates of the empty box's weight and underestimates of the heaviest box. Bingham reported a value of 7.84 lb (3.56 kg) for the mean unsigned distance of judgment means from actual weight; for the current experiment this value was 4.17 kg.

Experiment 2

The results of Experiment 1 demonstrate that British observers could discriminate weight levels with about the same level of random error, but with a lower level of quantitative accuracy, compared with the Runeson and Frykholm (1981) experiment using patch-light displays for Swedish observers. These results, showing a smaller range of judged values than the actual weight levels, are somewhat similar to results obtained for North American observers by Bingham (1993) using patch-light displays of actors lifting weight. Bingham argued convincingly that a contraction effect (e.g., Jones, 1986) could be operating in this and other magnitude estimation tasks employing midscale standards and repeated measurements. Given that we used full video (not patch-light) displays, we nonetheless were surprised by the magnitude of these systematic errors. British observers use pounds for smaller weights and (generally) kilograms and stone for heavier weights, and the idiosyncracies of applications of metrics for weight may be partly responsible for their conservative assignment of low and high weight values. It seemed worthwhile in this transatlantic collaboration to replicate Experiment 1, this time using the same full-view displays with North American observers.

Method

Displays. The full-view videotape displays in Experiment 1 were transferred onto a ¼-in. (0.635-cm) VHS tape, National Television Systems Committee video format (30 full frames per second) VHS tape, resulting in a small but noticeable decrement of video quality. All other materials and procedures remained the same.

Observers. Twelve undergraduates from an introductory psychology class participated in the experiment for course credit. Their ages ranged from about 18 to 22 years. Six observers viewed

[3] The simple correlation coefficient r is reported because we reason r is a more appropriate index of discrimination, compared with r^2, when averaging across observer. When discrimination is poor, the average value of r will approach zero, whereas the average value of r^2 is always positive and tends to increase as intraobserver error variance rises. The values of r^2 and mean r^2, nonetheless, are included to facilitate rough comparisons across published studies.

one of the two experimental tapes (depicting Actors AW and MH), and the remaining 6 observers viewed the second experimental tape (depicting Actors SV and AC).

Results and Discussion

Figure 2 shows the mean weight judgments as a function of physical weight level for both the current experiment (American observers) and Experiment 1 (British observers). Once again, judgments were a linear function of physical weight, with an average correlation of .84 for the American observers, compared with .86 for the British observers. The mean judgments were compared using an ANOVA, with weight (5) and actor (2 levels nested within experimental tape) as within-subjects variables and country (2) and experimental tape (2) as between-subjects variables; experimental tape and actor were modeled as random-effects variables. Because nested random-effects variables and their interactions can contribute to the expected mean squares of many of the remaining sources of variance under the null hypothesis (Myers, 1979), we computed quasi-F ratios (F') when necessary. The main effect of weight level was reliable, $F(4, 4) = 41.92$, $p < .001$, and accounted for 70% of the variance; in Runeson and Frykholm's (1981) experiment with patch-light actors, 68% of the variance was accounted for by weight. The effects of country, and the Weight × Country interaction, accounted for only 2% and 1% of the variance, respectively (neither F' was reliable). Although the discrimination of weight levels was good, the American raters showed a similar tendency to assign a small range of weight values to the experimental events, reducing appreciably their quantitative accuracy; the mean unsigned distance of judgment means from the actual weight levels

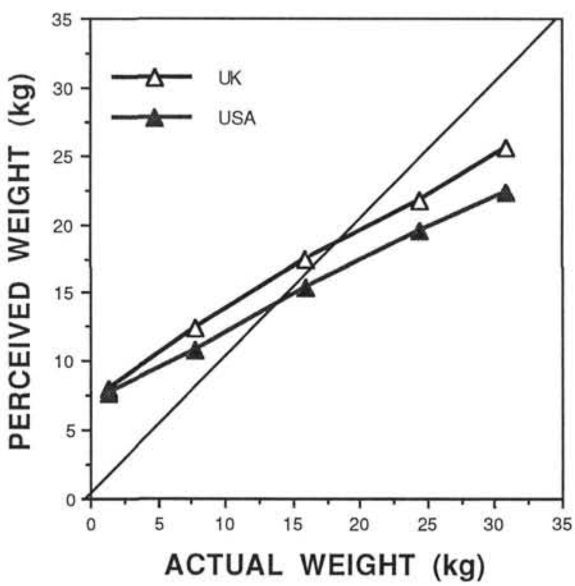

Figure 2. Perceived weight as a function of actual weight for each observer group (United Kingdom and United States) in Experiment 2.

was 4.67 and 4.17 for the American and British observers, respectively.

Therefore, it appears that the tendency to underestimate the range of experimental weights was robust in the current experiments and cannot be explained by reference to general level of familiarity with the pounds system of measurement. Note that a similar tendency to underestimate the range of experimental weights was observed in Bingham's (1993) study of judgments of lifted weight from patch-light displays. His speculation—one which we will investigate in future studies—was that Runeson and Frykholm's observers, showing impressive levels of quantitative accuracy, were substantially older and perhaps more earnestly engaged in the experimental task than his undergraduates, who participated for course credit.

Experiment 3

The results of Experiments 1 and 2 demonstrate an impressive level of weight discrimination from full-video displays of the actions of lifting and carrying, although the absolute level of judgment accuracy was modest. We next turned our attention to one of the major questions of these experiments: Will a similar degree of discrimination be evidenced from static views of the same event? Because of the vast number of static views available from an event lasting roughly 12 s (approximately 600 individual video frames, about 200 of which we would estimate to be reasonably discriminable from one another), an efficient procedure was needed to identify a relatively small number of action phases to be studied in a well-controlled and manageable experiment on the visual discrimination of lifted weight. To this end, Experiment 3 was designed as a first pass at assessing performance using 12 static views "sampled" at approximately equal intervals across the lifting-carrying event.

Method

Design. Each of 30 observers viewed 38 photographs of one actor lifting weighted boxes, 2 for practice and 36 to be judged categorically for weight (low, medium, or high). The set of photographs represented factorial combinations of two variables: weight (1, 16, and 31 kg) and action phase (12 levels). Three different sets of photographs were used, one for each of three actors, and one group of 10 observers viewed each of the three photographic sets. Displays were created using only Actors SV, AW, and AC because observers in Experiments 1 and 2 yielded the most accurate weight judgments when viewing these actors.

Apparatus. The original videotape of actors lifting five different box weights across 30 trials, described in Experiment 1, was used as the source of still images for Experiment 3. An S-VHS tape deck produced still images, which were displayed on a high-resolution 13-in. (33.02-cm) monitor. These still images were captured on color photographic print film using a 35-mm single-lens reflex (SLR) camera with a manual focus, 50-mm lens firmly mounted to a table and placed about 0.5 m in front of the monitor screen in a darkened room. Two sets of developed 6 × 4 in. (15.24 × 10.16 cm) photographic prints were arranged in inexpensive photo albums that displayed one print per page under a clear plastic protective sheet to be shown to the observers for weight level classification.

Production and arrangement of photographs. The shutter speed of the SLR camera was set at ⅛ s, slow enough to avoid image capture between the video half frames displayed at 1/50 s. For each of the three actors, the videotape was advanced to the fifth (last) trial of the 1-, 16-, and 31-kg block of lifting and carrying events, and 12 temporally distinct still images were photographed:

1. Before grip: Actor is stooped just before first grasping the box, about 1–2 hand lengths away from the box.
2. First grip: Actor's hands have just gripped the box but have not yet moved it.
3. First acceleration: Lifting has begun and box first accelerates upward.
4. One-third lift: Box has been lifted one third of its full carrying height.
5. Two-thirds lift: Box has been lifted two thirds of its full carrying height.
6. Upright: Actor is fully upright but has not begun to walk.
7. Step 1: Actor has taken the first step forward, and the heel of the forward foot has landed.
8. Feet together: Actor is between Steps 1 and 2, with one foot about to swing past the other.
9. Step 2: Actor has taken the second step forward.
10. At table: Actor has just stopped walking and is at the table.
11. Above table: The box is just about to be placed on the table but is still suspended completely by the actor's arms.
12. On table: Box has been placed on table, and the actor's hands are just about to release the box.

Two examples of these photographs are provided in Figure 3.

These particular 12 images were chosen because (a) they provided a relatively dense and thorough sampling of distinguishable action phases; (b) each still image was roughly equally spaced in time, generally 0.3–0.6 s apart; and (c) the images themselves could be identified reliably with reference to the position of the hands, the feet, or the box, independent of specific box weights, actors, or postures. The only factors that varied across box weights and repetitions within a position were the actor's posture, muscular tension, and facial expressions.[4] Two extra photographs were taken of the actor during a different lifting trial; these were used as initial practice stimuli. Thus, there were 38 photographs taken for each actor. Two randomized stimulus orders, one the reverse of the other, were generated for the 36 experimental photographs, such that each consecutive block of three photographs contained each of the three weight levels and each consecutive block of 12 photographs contained each of the 12 different action phases. The two sets of photographs were placed into separate photo albums using the two stimulus orders. This procedure was repeated for each of the three actors' photographs, yielding six photo albums of 38 photographs each.

Observers. Thirty observers, members of the staff and students at a British psychology department, served as raters. Their ages ranged from 18 to 86 years, and all were familiar with the pound system of weight measurement.

Experimental procedure. Each observer, one at a time, was given one of the photo albums, a rating form, and a pencil and was seated in a well-lit room. The following six points were explained to the observers: (a) The actor in the photographs was lifting one of three weighted boxes—3, 35, or 68 lb (i.e., 1, 16, or 31 kg, although only the pound scale was given); (b) each box weight would appear equally often; (c) the actor knew the box weight before lifting it; (d) the observer should select one of three box weight values (low, medium, or high) for each photograph; (e) each photograph should be viewed once and only once, in the fixed order of the photo album, but they could look at each photograph as long as they wished before moving on to the next; and (f) observers were encouraged, but not required, to write their impressions in the margins, stating which features of the actors appeared to be most informative. Five observers viewed and rated each of the six photo albums (hence, 10 observers per actor). The entire procedure lasted 10–20 min.

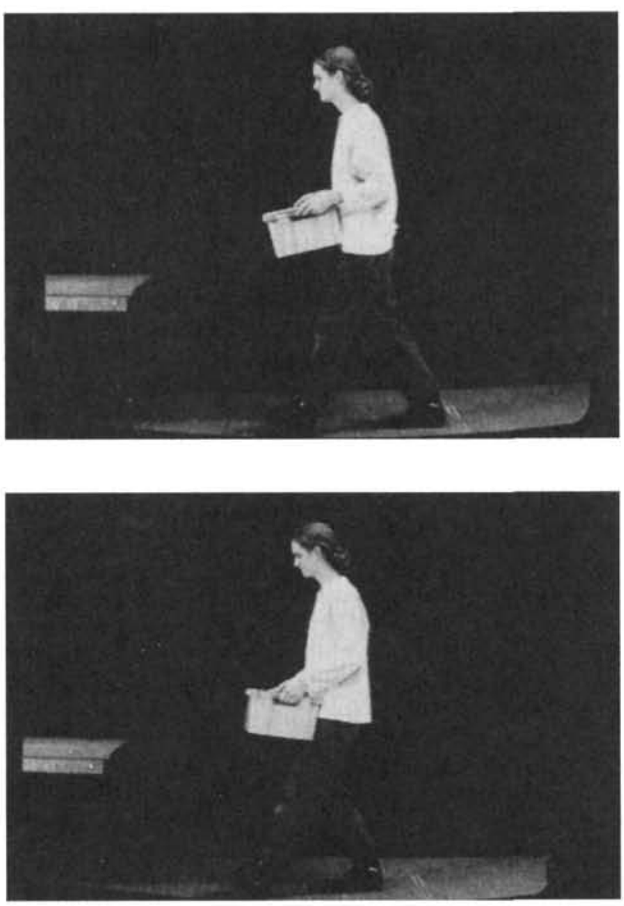

Figure 3. Examples of photographs (walking; Step 1) used in Experiment 3. Top: 1-kg box. Bottom: 31-kg box.

Results and Discussion

The performance was measured by the percentage of correct weight classifications within each of 12 action phases. Each observer was presented with just one example of each combination of three box weights and 12 action phases, and hence 100% represented three correct classifi-

[4] Given the limited horizontal resolution of the video display system (about 200 lines), facial expressions and muscular tension were generally not as powerful determinants of judgments as were postural structures. This view is corroborated by the impressions of the observers themselves when they were interviewed after their experimental trials.

cations.[5] Each observer's percentages of correct classifications were analyzed using a mixed 3 × 12 ANOVA, in which actor (AC, SV, and AW) was a between-subjects variable and action phase (12 levels) was a within-subjects variable. The only reliable effect was for action phase, $F(11, 297) = 5.41, p < .001$, which accounted for 14% of the total variance. The effect of actor and the Actor × Weight interaction, by comparison, accounted for only 1% and 6% of the variance, respectively. The main effect of action phase is graphically displayed in Figure 4, indicating at-chance performance for before grip (26%) and two-thirds lift (41%), a local peak at first acceleration (49%), and maximal performance corresponding to at table (68%). One-sample t tests revealed levels of discrimination reliably above chance for all action phases, except for before grip and two-thirds lift ($p < .05$, two-tailed, for 10 of the 12 action phases). Although average discrimination performance across action phases did not exceed 68% correct, we were impressed by the regularity of this function across actors.

The observers were invited to make a note on their response sheets about any photographs in which the impressions of heaviness or lightness seemed especially vivid and to try to identify what they believed created the impression. Their comments referred to the lean of the body, the bracing of the box against the trunk, hunched shoulders, the position of the feet (wider apart for heavier boxes), facial expressions, and the angle at which the box was held. Curiously, 2 observers referred to the "nonchalance" of Actor SV when carrying the light box in Phases at table and Step 2; they noted the total lack of bowing of the shoulders, the easy posture of the forearms, and the relaxed form of the hands.

This initial study of the effectiveness of the static displays in representing the dynamics of the lifting events has revealed that observers were capable of reliable discrimination between the various weight levels, but it also seems to be the case that some displays were more effective for yielding good performance depending on which phase of the lifting-carrying event they represented. There may be several reasons for these variations in performance, including some phases provide informative structures that are more easily detected and some phases contain more numerous or redundant structures that covary with the dynamics of the action. It would, of course, require a separate set of experiments to identify convincingly the particular static structures that specify dynamics in these displays. Our studies, however, allowed us to treat observers as, in effect, "information detectors." Insofar as the displays can be shown to support reliable judgments, we can conclude that there must be information available in the displays. However, performance-based assessments of the richness and quality of the available information necessarily constitute lower-bound estimates. Failure to make reliable judgments does not imply the absence of information, nor does moderate performance preclude the possibility, for example, that specially trained observers, such as dance or gymnastics instructors, might be able to use information disregarded by the untrained observers who had taken part in our study.

Experiment 4

This experiment was designed to provide a sensitive test of the capacity of observers to make accurate judgments of weight from static depictions of a person lifting and carrying a box. Experiment 3 indicated better ordinal judgments of weight from the photographs of carrying the box than those of lifting the box, an interesting finding given that in previous studies using patch-light video displays, it was postural shifts associated with lifting that observers usually identified as being the most informative (Runeson & Frykholm, 1981). In addition to lifting and carrying, we included photographs of individuals preparing to lift a box to determine whether the perception of intention to lift, shown previously with kinematic patch-light displays (e.g., Runeson & Frykholm, 1983, Experiment 2), also would be evidenced in static depictions of these same postures. In our procedure, the actors knew the weight of the boxes before each photographed lifting and carrying event both because they were told the exact weight and, after the first lifting trial, from their own experience. Therefore, four static phases of the action were chosen for the major experimental manipulation in Experiment 4: preparing to lift a box, lifting a box off the ground, carrying a box to the table, and placing a box on the table.

Method

Design. Each of eight observers viewed 160 photographs in a completely within-subjects design and provided weight judgments. The set of photographs, arranged in eight photo albums to show one actor and one action phase at a time, yielded factorial combinations of the following four variables: Actor (2) × Phase (4) × Weight (5) × Repetition (4). Thirty-two additional 16-kg standard photographs—one for each combination of actor, phase, and event repetition—were included with the experimental set, resulting in a total of 192 photographs.

Observers. Eight students and staff at a North American university psychology department, ranging in age from 26 to 45 years, served as observers. None was familiar with the research problem or the two actors shown in the set of photographs.

Apparatus and photographic procedure. The same equipment and general photographic procedure, described in Experiment 3, was used to produce 192 photographic images. For each of two actors (AC and AW), photographs were taken for each of six weight conditions (the five weight levels plus an extra 16-kg standard) from four distinct action phases:

1. Before grip: Actor stooped before the box is first grasped, about 1 to 2 hand lengths away from the box.
2. One-half lift: Box is lifted one half of its full carrying height.
3. Step 1: Actor has taken the first step forward, and the heel of the forward foot has landed.
4. At table: Actor has just stopped walking and is at the table.

Criteria were established for choosing still frames consistently across actors and weights to represent the four action phases on the basis of the position of the hands (when approaching the box),

[5] One of the three photographs for Actor AC at action phase Step 2 was missing from the stimulus set because, on one particular event, this actor made only one step forward before lowering the box to the table.

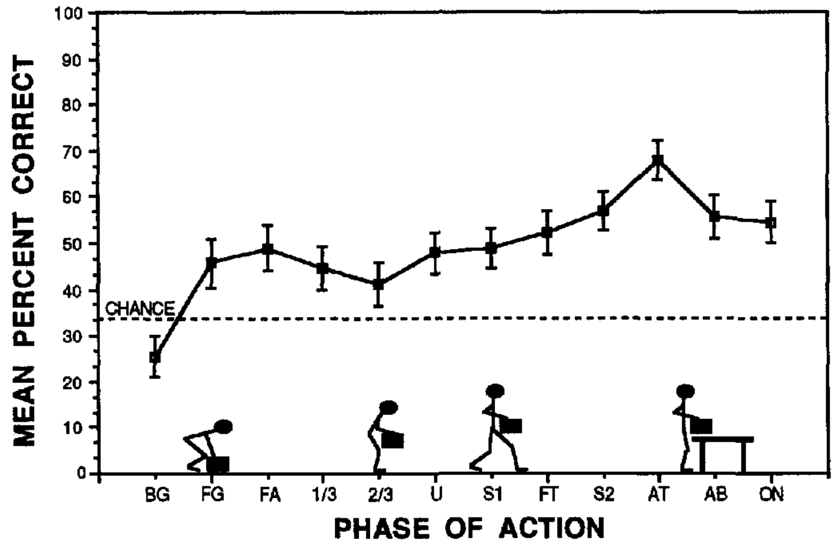

Figure 4. Mean percentage of correct classifications (and standard errors) of box weight as a function of static displays of action phases (12 levels) collapsed across observers and actors in Experiment 3. Phases of action: before grip (BG), first grip (FG), first acceleration (FA), one-third lift (⅓), two-thirds lift (⅔), upright (U), Step 1 (S1), feet together (FT), Step 2 (S2), at table (AT), above table (AB), and on table (ON).

the box (when lifting), and the feet (when carrying and when at the table), such that the only factors that varied across actors and weights within a position were the actor's posture, muscular tension, and facial expressions. Four repetitions of each of these weight–phase combinations were photographed using the last four of the five lifting event trials on the original videotape. Each of eight inexpensive photo albums displayed twenty-four 4 × 6 in. (10.16 × 15.24 cm) glossy color photographs of only one actor in one phase of the lifting and carrying event; each photograph appeared on a separate page under a clear plastic protective sheet. The four photo albums for each actor were arranged in a different order for each observer, based on a Latin square pattern, to counterbalance possible carryover effects from one action phase to another. Half the observers first viewed the four photo albums for Actor AC, and the remaining observers first viewed the photo albums for Actor AW. A different randomized stimulus order was used within each of the eight photo albums, designed with the following constraints: (a) Each consecutive block of six photographs represented five different weight conditions with an additional 16-kg standard condition; (b) each consecutive block of four photographs represented one of each of the four event repetitions; and (c) a standard 16-kg photograph appeared first in the album and then appeared after every five to seven experimental photographs. This procedure of varying the position of the standard was adopted to make it less likely that observers would guess that there was a fixed number of weights and hence inflate the discrimination measure.

Experimental procedure. Each observer agreed to view two albums of 24 photographs on each of four testing sessions spaced no more than 1 week, and no less than 1 day, apart. On the first session, each observer was given a photo album, a rating form, and a pencil and was seated in a well-lit room. The following instructions were printed at the beginning of each book and were read to each observer on the first testing session:

1. Please view each photograph, one at a time, and make your best judgment of the weight of the box in pounds. For some of the photographs, the weight is provided to give you a standard for making your judgments; this standard will always be a 35-lb box. The remaining photographs show persons lifting, or about to lift, a covered box that contains one of a variety of weights.

2. Please view the photographs in consecutive order when making your judgments, and do not view previous or subsequent photographs. View only one photograph at a time, and base your judgments on any features of the photograph that you believe are informative about the weight of the box.

3. Please note also that there is no deception in this study; the actor knew the weight of the box before each lift and was instructed to lift the box in a way that would be most natural and comfortable for him.

Each of the four sessions lasted 15–25 min.

Results and Discussion

Figure 5 shows differential performance for static depictions of lifted weight across the four action phases; the function for the full video display (Experiment 1, the same two actors but a different group of observers) is included for comparison. The best discrimination of weight levels occurred for the photographs of actors in an upright position, either carrying the box (Step 1, mean r = .73, collapsed across observers and actors) or standing as they placed it on the table (at table, mean r = .74). This level of performance is impressive, although it is not as high as that for observers who viewed these same two actors in the full video condition of Experiment 1 (mean r = .92). All discrimination functions across the four action phases and two actors were flatter than the ideal functions, showing consistent underestimates of the range of lifted weight. For example, the

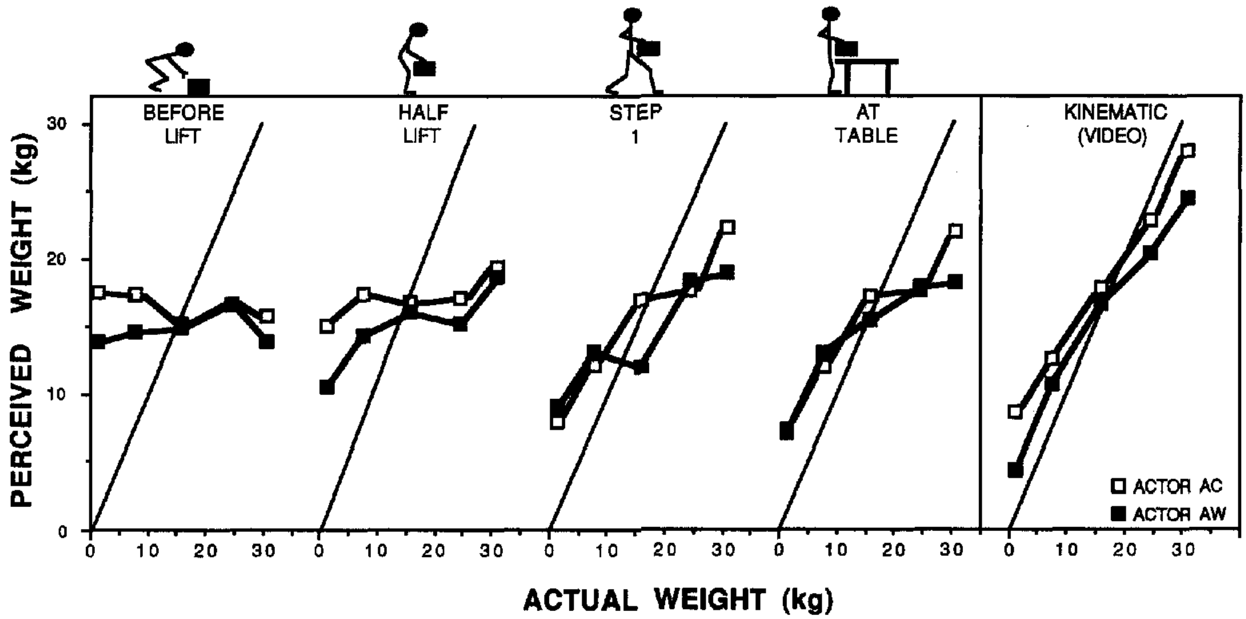

Figure 5. Perceived weight as a function of actual weight for static depictions from four action phases (before grip, half lift, Step 1, and at table) and two actors (AW and AC) in Experiment 4. Functions for kinematic displays (Experiment 1) are provided as a comparison.

regression line corresponding to the at table action phase yielded an average slope of only .46, with average judged weights ranging from about 7 to 20 kg (compared with an actual range of 1–31 kg), collapsed across actors and observers. The average unsigned deviation of judgment means from the actual weight values, a general index of systematic errors, ranged from 5.79 (at table) to 9.51 kg (before grip), collapsed across the two actors. By comparison, the average unsigned deviation for the full video display (Experiment 1) was 3.60 kg for these same two actors.

The within-cells standard deviations of weight judgment provided another measure of performance, the level of random errors. Dispersion was lowest for action phase Step 1, when the actor was carrying the weight while walking (SD = 3.57 kg, pooled across two actors and five weights), and highest for before grip (4.96). Across all actors, weights, and action phases, the within-cells standard deviation was 4.17 kg.

It would be a mistake to conclude from these average functions that weight perception is not possible for the photographs of an actor in the before lift and half-lift action phases. Table 1, displaying values of r, r^2, slope, and intercept for individual observers, shows that even for the depiction of intention to lift a box, 1 of the 8 observers correctly discriminated weight levels for one of the two actors (AC). For the half lift, 3 of 8 judges for Actor AC, and 5 of 8 judges for Actor AW, showed reliable and correct tracking of the weight levels. We can infer that information for the perception of lifted weight exists in at least three of the four action phases examined in the current experiment.

Experiment 5

The results of Experiments 3 and 4 yielded an unexpected finding: Static displays of carrying a weight yielded better performance than static displays of lifting. Initially, we had surmised the opposite because observers of kinematic displays informally report that it is the lifting phase that gives the most vivid impression of weight, and static displays of lifting may have contained sufficient correlated configural structure to permit reliable weight discrimination. Because our ultimate goal was to move toward an understanding of the informational bases in configural structure for visual weight perception—specific structures of posture, facial expressions, or patterns of muscular contraction under the skin—it would be helpful to compare directly the performance profiles for these static displays along the action path to matched kinematic displays across brief, local regions of the action path. Such a comparison would demonstrate where along the action path perception of dynamics depends critically on kinematic structure and where informative configural structure remains when kinematic structure is removed. Of course, this type of direct comparison between "kinematic + static" (video) versus "static" (photograph) conditions is only possible with methods, such as ours, that use full-image (not point-light) displays.

To this end, two final experiments were designed. Experiment 5 was a first pass at identifying local action phases with informative kinematic or configural structure by asking observers to view slow-motion displays of the action and select brief moments that appear to reveal the weight of the box. This technique is similar to the measurement of "breakpoints"—points of definition in the stream of behavior—

Table 1
Correlation Coefficients, r^2, Slopes, and Intercepts (in kg) as a Function of Actor, Phase of Action, and Observer in Experiment 4

	Actor AC				Actor AW			
Observer	r	r^2	Slope	Intercept	r	r^2	Slope	Intercept
				Phase 1: Before grip				
1	−.54*	.29	−.30	26.76	−.15	.02	−.06	17.69
2	−.30	.09	−.22	19.95	.06	.00	.03	15.42
3	−.21	.05	−.08	16.78	−.31	.09	−.08	17.23
4	.45*	.21	.15	14.51	.14	.02	.04	16.78
5	−.21	.04	−.05	15.42	.43	.19	.17	11.79
6	.05	.00	.02	14.06	.10	.01	.06	6.80
7	−.04	.00	−.02	15.87	.16	.03	.10	12.24
8	.16	.02	.04	16.78	−.14	.02	−.04	16.78
M	−.08	.09	−.06	17.52	.04	.05	.03	14.34
				Phase 2: One-half lift				
1	.78*	.60	.41	12.24	.57*	.33	.17	13.15
2	.34	.11	.16	15.87	.40	.16	.27	12.24
3	.62*	.39	.19	14.06	.58*	.33	.18	14.51
4	.56*	.31	.16	14.51	.55*	.31	.24	13.15
5	−.41	.17	−.14	16.78	.74*	.54	.33	8.16
6	.23	.05	.08	13.15	.43	.19	.18	3.17
7	−.25	.06	.13	22.22	.70*	.49	.47	9.52
8	.36	.13	.11	14.97	−.26	.07	−.10	18.59
M	.28	.23	.11	15.48	.46†	.30	.22	11.56
				Phase 3: Step 1				
1	.76*	.58	.52	9.52	.76*	.58	.30	11.79
2	.92*	.84	.83	2.27	.90*	.81	.77	0.45
3	.89*	.78	.33	10.43	.41	.17	.10	14.06
4	.49*	.24	.24	12.24	.87*	.75	.46	7.26
5	.86*	.74	.33	9.52	.87*	.75	.25	11.34
6	.73*	.53	.47	3.63	.57*	.32	.35	3.17
7	.80*	.64	.59	7.26	.28	.08	.16	11.79
8	.85*	.72	.29	10.88	.70*	.49	.25	11.79
M	.79†	.63	.45	8.22	.67†	.49	.33	8.96
				Phase 4: At table				
1	.80*	.64	.35	11.34	.69*	.48	.27	11.34
2	.88*	.77	.73	3.63	.79*	.62	.63	3.17
3	.76*	.58	.51	7.26	.65*	.42	.19	12.24
4	.75*	.56	.40	8.16	.82*	.68	.53	7.26
5	.77*	.59	.33	9.07	.78*	.61	.34	7.26
6	.83*	.69	.47	5.90	.56*	.32	.33	5.90
7	.77*	.60	.61	5.90	.58*	.34	.36	9.52
8	.86*	.73	.27	12.24	.54*	.29	.20	12.70
M	.80†	.65	.46	7.94	.68†	.47	.36	8.67

* One-sample t test for correlation coefficient, $p < .05$. † One-sample t test for mean correlation coefficient, $p < .05$.

that was used by Newtson and colleagues for analyses of structure in action and interaction (e.g., Newtson, 1980, 1990; Newtson, Hairfield, Bloomingdale, & Cutino, 1987). In Experiment 6, we examined actual performance when viewing isolated and brief kinematic displays.

Method

Apparatus. The experimental videotape from Experiment 1 was edited for use in the current study. In addition, a VHS tape deck, capable of slow-motion playback, was used for the presentation of the videotaped actions. An IBM-compatible PC equipped with a vertical interval time code card and linked to the VHS tape deck was used to record keypress responses and the corresponding video frame time code. The acts were displayed on a 27-in. (68.58-cm) color video monitor.

Observers. Six members of a university psychology department in North America (staff and students) served as observers. Their ages ranged from 26 to 59 years.

Procedure. The observers, one at a time, were instructed to view blocks of three different lifting and carrying events—in which each block depicted one actor with one box weight—and to identify three particular moments in the third event in which the display most vividly reflected the weight of the box. Each event, lasting 4–6 s, began with the actor approaching from the right, lifting the weighted box from the ground, carrying the box to the left, and placing the box on the table. The observers pressed a computer key to signal each of their three choices of "informative" moments, which may have been, for example, the start of the lift, a particular shifting of the stance before walking, and a moment as the box was being placed on the table.

We decided to present the third event of each block in slow motion (about half speed) so that observers could more easily locate and select the local action phases that appeared most informative during the first two normal-speed presentations. Three different acts with the same actor and weight were used in each of the blocks, rather than three repetitions of the exact same event, so that observers could anticipate informative action phases but not have the opportunity to detect subtle structures perceivable only in the less common situation of repetitive viewing. Nonetheless, the three actor–weight repetitions were remarkably similar, and we suspect that many judges would not have noticed that the three events were different had we not told them so. As in the previous experiment using videotapes, all events were displayed without sound.

With this procedure, each observer viewed nine blocks of three events selected from the pool of videotaped lifting and carrying events in Experiment 1. Across the nine blocks of event displays, factorial combinations of the three actors (SV, AW, and AC) and three box weights (1, 16, and 31 kg) were used in a fixed order for all observers: SV-31, SV-16, SV-1, AW-1, AW-31, AW-16, AC-1, AC-16, and AC-31. Displays were created using only Actors SV, AW, and AC (not MH) because observers in Experiments 1 and 2 yielded the most accurate weight judgments when viewing these actors. Within each of the nine actor–weight blocks, three consecutive events (Trials 3–5) were edited from the original videotape.

Results and Discussion

Figure 6 displays the entire set of optimum action-phase judgments as a frequency polygon, with action phase partitioned into 12 sequential, mutually exclusive, and exhaustive partitions. Each partition begins with one of the 12 action phase markers used in Experiment 3. Of course, defining action boundaries in this manner yielded variability in temporal duration depending on the particular actor and the weight of the box being lifted. All the same, we were most interested in discovering how unitary these identifiable segments are as apparently informative or not-so-informative action segments rather than in their duration per se. Averaged across nine judged lifting and carrying events, each action phase lasted 0.33–0.56 s.

The most prominent feature of Figure 6 is the peak at the "first acceleration" action phase, the activity between the first vertical movement of the box and one third of its carrying height. Informal comments by the observers suggested that the speed of the lift, coupled with the postural adjustments and apparent muscular strain, were informative during this action phase. These data are consistent with the informal observations reported by Runeson and Frykholm (1981), and with our own discussions with observers in Experiment 1. Recall that static displays drawn from around this action phase did not yield reliable discriminations for most observers; it appears that kinematic structures, rather than configural structures, support the perception of heaviness in these changing displays.

The next action phase judged most informative occurred just after the box is two thirds of its final carrying height until the actor had taken his first step forward. Here, actors adjusted their stance before walking with heavy objects while they held the box more or less close to the body with varying degrees of bend of the elbows and backward lean of

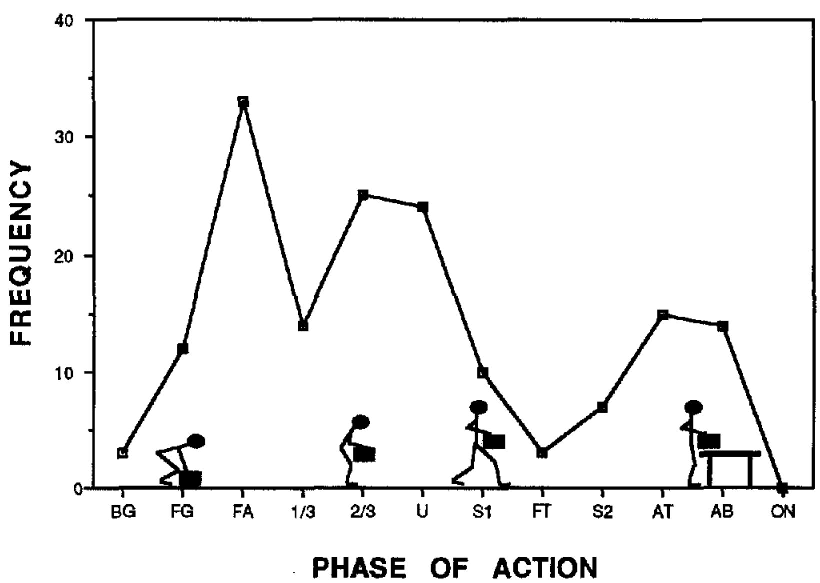

Figure 6. Frequency of optimum point judgments from kinematic displays as a function of phase of action (12 levels), collapsed across three actors (AW, SV, and AC) and three box weights (1, 16, and 31 kg) in Experiment 5. Phases of action: before grip (BG), first grip (FG), first acceleration (FA), one-third lift (⅓), two-thirds lift (⅔), upright (U), Step 1 (S1), feet together (FT), Step 2 (S2), at table (AT), above table (AB), and on table (ON).

the torso. Unlike the lift phase, this prewalking phase seemed to yield informative structures in both static and kinematic displays because of the presence of configural properties that were not related to velocity of movement, such as the manner of holding the box, in addition to the kinematic properties described earlier.

Another peak, distinct from those near the lifting phase, occurred when the actor approached the table and began to place the box on its surface. In this portion of the videotape, actors with light boxes often held the box farther from their bodies as they placed it on the table, and actors with heavy boxes showed signs of muscular strain in their faces, necks, and arms. Static displays of these same local action phases yielded the best performance because the movement of the heavier boxes away from the body and toward the table appeared to have a measurable effect on global posture as (a) the center of mass of the person-box system changed and as (b) the person's muscular strength was taxed, leading to constraints on the range of possible arm and hand movements.

One perspicacious woman declared that the actors appeared to place some boxes "more carefully" on the table "so as not to damage it" (i.e., the table surface), and these boxes were judged to be more massive. We found this observation most interesting, in part because it illustrates that the culturally appropriate uses (and abuses) of objects in relation to one another—in this case, an affordance relation of damaging-damageable—also can specify their physical properties. In a similar vein, observers in Experiment 1 often commented on the poor lifting technique of Actor MH, which seemed to have perturbed their estimations of the weight of the box he lifted; there also is the propriety of "looking after one's own back" and the culturally shaped, safe ways of manipulating objects can further specify their affordances (see also Hodges & Baron, 1992).

Experiment 6

In this final experiment we compared weight judgment discrimination and accuracy across four brief kinematic display types, each lasting about 1.0–1.5 s. Whereas Experiment 5 required observers to guess which local action phases were most informative about weight within the entire kinematic display of lifting and carrying, the current experiment assessed their actual performance in judging weight when each display was restricted to a brief interval during the same four action phases sampled previously in static displays: the action just prior to the lift, the action of lifting, walking two steps, and placing the box on the table. This procedure allowed a direct comparison of performance on brief kinematic displays with photographically "arrested" displays captured within the same action phases. By examining changes in performance at particular action intervals when kinematic structure was added, we narrowed the range of possible informative structures in photographs of human action.

Method

Design. Two groups of 12 observers (one group for each of two actors) viewed 60 brief kinematic (videotape) displays, representing factorial combinations of action phase (4), weight (5), and repetition (3). Twelve additional 16-kg standard displays—one for each combination of phase and repetition—were included in the experimental set, resulting in a total of 72 displays. The dependent variable was weight judgment in pound units.

Apparatus and videotape editing. The experimental videotape from Experiment 1, containing 12-s displays of actors lifting and carrying boxes, was edited to produce eight experimental videotapes (VHS tape and National Television Systems Committee video format), displaying brief kinematic slices of action. Each experimental tape displayed only one actor (AC or AW) and one of four action phases chosen to bracket the action phases depicted in the photographic displays of Experiment 4:

1. Before lift: The interval before the actor's lift of the box, up to the first grasp of its handles.
2. Lift: The interval through the grasp, lift, and upright position.
3. Walk: The interval of walking approximately 1.5–2 steps.
4. Place on table: The interval of placing the box on the table.

The final set of kinematic displays showed some temporal variability, ranging in duration from about 1.0 to 1.5 s. We could not avoid this situation because of the unavailability of an automated system for editing brief videotaped displays, together with our intention to guarantee that each display type be limited to one of the four the action phases defined earlier. Because the displays were so rapid and easily missed, we arranged each display as a double presentation, in which the observer was first given the opportunity to view the event without responding, and, after a 2-s blank interval, was shown the same brief event again and required to make a weight judgment. These double-presentation displays were arranged on eight experimental tapes, with each containing three blocks of six brief events (five experimental weights plus one standard) for one of two actors in one of four action phase, based on the same randomly ordered events within actors in Experiment 1 and 2. All events were displayed on a 27-in. (68.58-cm) color video monitor.

Observers. Twenty-four students at a North American university, ranging in age from 18 to 22 years, participated for course credit. None was familiar with the research problem or the two actors.

Experimental procedure. Twelve observers viewed four experimental tapes in succession (before lift, lift, walk, and place on table), each of which depicted one of the two actors (AC or AW) in 18 brief action segments (15 experimental events and 3 standard events). The remaining 12 observers viewed the second set of four experimental tapes, which displayed the other actor in each of four action phases. To control for possible order effects, we used a Latin square randomization scheme to present the four experimental videotapes in four orders across the set of 12 observers in each of the two observer groups. All observers were seated, up to 3 at a time, 2 m in front of the monitor in a normally lit room. Observers were given a pencil and a response form on which to record their weight judgments in pound units. As in our previous experiments, the videotapes always were displayed without sound.

Results and Discussion

Figure 7 displays differential performance for the brief kinematic displays across four action phases; the function for the full-video display of Experiment 1 for these same

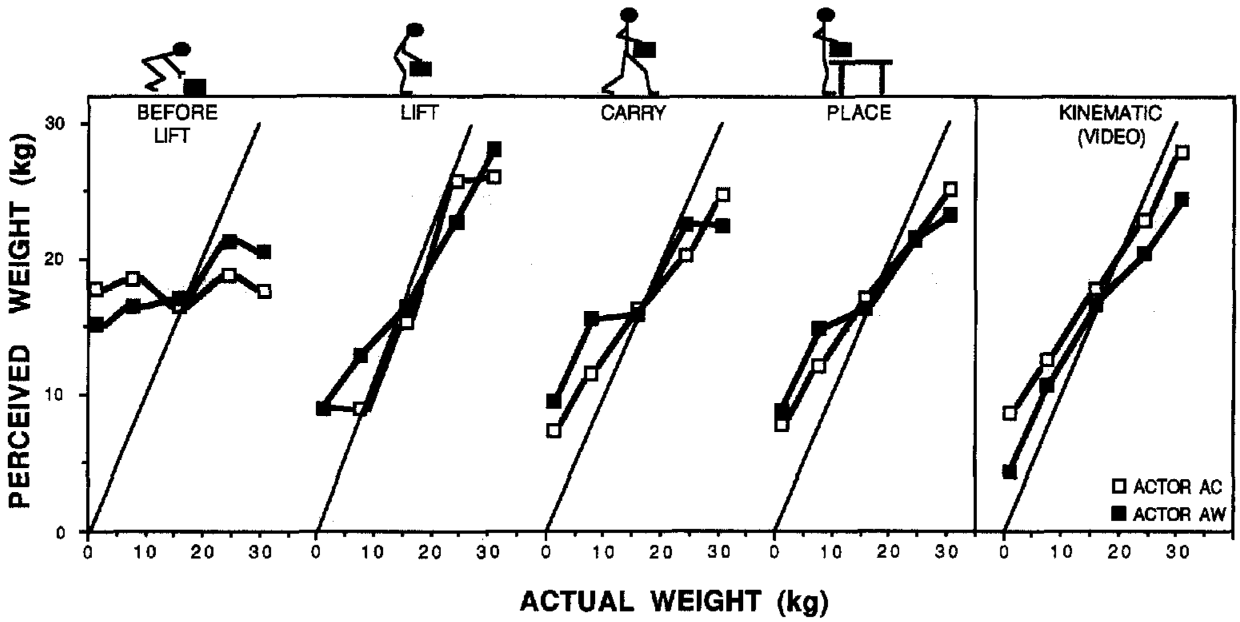

Figure 7. Perceived weight as a function of actual weight for brief (1–2 s) kinematic displays from four action phases (before lift, lift, carry, and place) and two actors (AW and AC) in Experiment 6. Functions for video displays (Experiment 1) are provided as a comparison.

two actors is included for comparison. As expected, performance was not high for the kinematic displays of actors approaching and grasping a box just before the lift, although for one actor (AW) the average correlation of actual with judged weight was reliably above chance at .46 (average regression slope = 0.21, average intercept = 14.79 kg). Averaged across actors, the level of performance for observers of these brief kinematic displays of action phase lift (r = .85), walk (r = .84), and place-on-table (r = .85) approached that obtained from observers of the 12-s full-video displays of the same actors (Experiment 1, r = .92; Experiment 2, r = .91). A Phase (4) × Actor (2) × Weight (5) mixed ANOVA revealed that 32% of the variance was within cells, 52% was due to weight, 12% was due to the Phase × Weight interaction, 2% was due to the Actor × Phase × Weight interaction, and less than 1% was due to the phase main effect. Only these effects were reliable ($p <$ .05). The pooled within-cells standard deviations ranged from 3.48 (carry) to 5.30 (before lift), with a mean of 4.35 kg. By comparison, the mean within-cells standard deviation for the static displays (Experiment 4) was 4.17 kg.

Whereas discrimination of weight values for three of the four action phases was good, the absolute level of accuracy was moderate, in particular for the extreme experimental weight values. As was true for the previously described experiments, all functions had a lower-than-ideal slope, ranging from .11 (before lift) to .67 (lift), averaged across actors. The average unsigned distance between the judgment means and the actual weight values ranged from 8.42 (before lift) to 4.64 kg (at table), collapsed across actors. These measures of systematic errors are not far off from those for the static displays of the same two action phases, 9.51 (before lift; Experiment 4) and 5.79 (at table; Experiment 4).

Figure 8 shows a comparison of performance with brief kinematic displays and that using matched (embedded) static displays of Experiment 4 in a simplified format, in which the mean correlation across observers is graphed as a function of action phase, display type, and actor.[6] Two features are noteworthy. First, the functions for the brief kinematic displays were always higher than those from the static displays, yet, across actors, the differences between the correlation values for static versus dynamic displays were less than .12 for the walk and place-on-table phases. We were surprised by the low magnitude of these differences. It is possible that the kinematic displays of walking and placing on table, showing slow and controlled movements, provided observers with informative structures that were primarily configural.

Second, there was an extreme discrepancy between the correlation coefficient values of the kinematic and static displays of the lift, in which the difference ranged from .45 (Actor AC) to .51, about half the possible scale range (assuming zero as a minimum) and five times the discrepancy between static and kinematic display performance for the walk and place phases. This difference is even more impressive when one considers that the total viewing time of each kinematic lifting event did not exceed 3 s, whereas

[6] An analysis of variance was not calculated because of extreme heterogeneity of variance across the display types used in Experiments 4 and 6. Nonetheless, the differences relative to the standard errors were robust, and the essential pattern was replicated across actors.

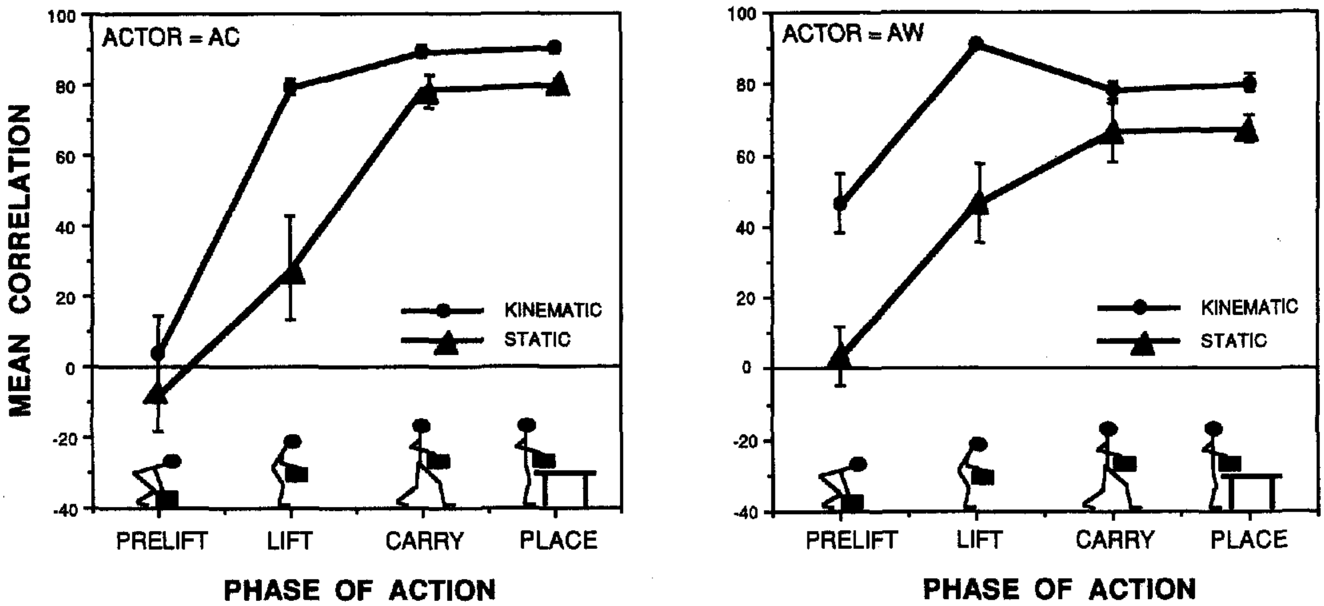

Figure 8. Mean correlation between actual and perceived weight (and standard error) as a function of display type (static and kinematic), phase of action (prelift, lift, carry, and place), and actor (AC and AW), Experiments 4 and 6.

observers could view the static depictions as long as they wished (in some cases, lasting more than 1 min). It appears that even a brief glimpse of the event kinematics reveals informative relations with the mass of the box, a finding reminiscent of Johansson's (1973) report that identification of persons in action is possible on the basis of 200-ms point-light displays. These data fit well with the observers' impressions of the lift phase in Experiment 5; the vast majority of most informative choices occurred during the brief course of the lift.

Static displays of actors lifting boxes, on the other hand, posed a much more difficult task, although 5 of 8 observers of Actor AW showed reliable tracking of weight levels. We think, having viewed these displays many times and from our discussions with raters, that observers of static displays of lifting can show better performance if they are attuned to specific configural features (such as straddling of the feet and legs), global configural structures (something resembling the "spread" of the body–box system around a perceived center of mass?), or subtle signs of muscular exertion in the hands, shoulders, and neck; these and other hypothesized informative structures will be examined formally in subsequent experiments. The fact that midlift postures normally are only glimpsed also may have contributed to overall low visual weight discrimination; these photographs, along with displays of the prelift, are striking in their novelty. Observers of kinematic displays, on the other hand, also have a set of informative and easily detected features, such as the delay between the grip and the initial acceleration of the box, the movement path of the box (e.g., heavier boxes move in toward the body as they are lifted), and the peak velocity (lighter boxes generally are moved faster).

General Discussion

A primary finding of the current experiments was that static photographic displays, based on particular phases of the activity of lifting and carrying a box, yielded reliable discriminations of box weight, in some cases approaching levels of performance based on brief kinematic slices and even the complete video of the entire lifting-carrying event. In fact, the best levels of discrimination from our static displays (e.g., AC; at table, mean r = .80) exceeded the lowest level of discrimination for one actor on the 12-s kinematic (full video) display (MH; mean r = .74). These findings alone underscore the tremendous specification power of the natural visual array, which can yield subtle yet informative structures for perception of dynamics even when sampled in a static image. Within modern technological societies, photographs are enormously useful, such as those used in a diverse array of training manuals (e.g., automobile repair, surf fishing, procedures for restraining people), and facial photographs when used to locate and identify sought-after individuals. Certainly, the use of kinematic displays of facial or whole-body movement will permit greater levels of discrimination, as shown, for example, in a recent study on learning ballet sequences (Gray, Neisser, Shapiro, & Kouns, 1991). It is not necessary, however, for satisfactory performance in many of the identification tasks based on photographs that normally are encountered in everyday contexts.

A second finding was that, although performance based on the static displays was sometimes comparable to that for brief kinematic displays sampling the same phase of the action, there also were striking discrepancies. There was a precipitous drop in discrimination performance for the static displays compared with the brief kinematic displays of the lift, a decrease of about .45 in the correlation coefficient value, compared with the reduction observed for static versus kinematic displays of walking or placing the box on a table, about .11. In our kinematic display tasks, observers almost always reported that it was the initial moments of lifting that appeared most informative about the weight of the box. These reports were given spontaneously during the full-video experiments and were corroborated by the results of Experiment 5, in which observers assigned "optimal points" to the lifting interval along the path of the movement. Using brief kinematic displays (Experiment 6), the lift was associated with high performance (r = .85 across actors). One might have expected that the static displays taken from the same local region of the lifting movement pattern also would have yielded fairly good weight discrimination; although the kinematics were frozen out of the visual structures, perhaps these portions of the movement should have been rich enough in covariate static structures to support reliable judgments. Our data clearly show that this was not the case. The average correlation between actual and judged weight was only .37 for static depictions of the lift phase of action. If there were informative structures in photographs of the lift—and, as explained earlier, we have reason to believe there were—most of our observers were not detecting them. These findings, considered in isolation, would seem to confirm Merleau-Ponty's misgivings about photography as opposed to painting: "The instantaneous glimpses, the unstable attitudes, petrify the movement, as is shown by so many photographs in which an athlete-in-motion is forever frozen" (Merleau-Ponty, 1961/1964, p. 185).

Our data do indicate, however, that certain static photographs allowed the observer to "thaw out" the action, if only part way. The best weight discrimination with static displays—nearly as good as discrimination from brief kinematic displays—was evidenced with depictions of walking with the box or standing while placing the box on a table. This contrasts with the low performance associated with photographs, but not videos, of the lifting phase. Clearly, the static and kinematic displays behave in different ways, although we must remember, of course, that static displays cannot re-present all the information available in kinematic displays. On the other hand, it is entirely possible that precisely because photographs are static, and hence can be "held" not just by the hand but also the eye, they may alert the observer to certain aspects of posture not readily noticed in a changing display. Further study of the precise postural configurations in our displays, drawing on principles of biodynamics (e.g., Bernstein, 1967), will be necessary to discover the informational bases of our observers' perception of lifted weight and other dynamics in these photographs. Of course, a complete understanding of this skill also would address the muscular strains and facial expressions that accompany movements, an understanding that is sought by all serious students of sculpture and painting.[7]

Limiting our comments to postural form, we offer one preliminary line of reasoning for why some static views succeed and others fail at the depiction of dynamics. When a person lifts a box, the entire posture transforms, and that transformation will take on a characteristic "shape" depending on the magnitude of the additional forces on the arms as a consequence of hefting the box and the intended movement end point (e.g., lift to stand vs. lift to walk). More massive boxes will exert considerable inertial forces on the body after the actor's effort to move the box, contributing to final shape as the actor–box system settles into a stable pattern of standing or walking. Most brief glimpses of the lifting action will be intrinsically ambiguous because the posture of the actor depends on the time course of the forces applied to the box, as well as the initial position and planned movements of the actor in relation to the box. For example, even a fairly massive box can be held far in front of an actor without compensatory backward lean during a lift if the force is applied quickly and the actor steps backward. A heavy barbell could be, literally, "light as a feather" and held easily with one hand above the head—for a brief moment—when its acceleration moves through zero at the peak of the lift. In addition, a static depiction taken from this small window of time may be difficult to describe, not because the observer cannot see dynamics, but because the question of weight is ambiguous. Although a judgment of the barbell's weight may be requested, observers may be judging pressure—the weight bearing on the body—that at that moment would indeed be slight. If the actor continues this trick for another few seconds, posture will (painfully) reveal dynamics. Quick actions, and in particular those involving greater hefted masses, can introduce temporal

[7] Many outstanding examples of an artist's attention to the details of skeletal–muscular form and function can be found in any of several publications on the life and works of Thomas Cowperthwaite Eakins (1844–1916), such as Porter's (1959) concise overview, an early text by Goodrich (1933), a later and more detailed study by Hendricks (1974), and the recent catalogues of the Hirshhorn Museum and Sculpture Garden (Rosenzweig, 1977) and of the Philadelphia Museum of Art (Sewell, 1982). Of particular interest is Eakins's (1894) presentation to the Academy of Natural Sciences of Philadelphia, where he described his own observations and mechanical models of the muscles of a horse pulling a cart:

> One is never sure that he understands the least movement of an animal, unless he can connect it with the whole muscular system, making, in fact, a complete circuit of all the strains. The differential muscles once understood, it is less difficult to connect nearly all the other great muscles with the principal movement of the animal, that of progression in the horse; and to understand, roughly, the combinations necessary for other movements. (p. 180)

Those wishing to read more about Eakins's scientific study of locomotion may consult the work of Schendler (1967). In his own highly disciplined manner, Eakins wrestled with basic concepts of biomechanical coordination (e.g., Bernstein, 1967; Turvey, 1990) to understand and depict animal action.

lags in the dynamics–posture covariation because the energy that shapes posture is temporarily transferred as kinetic energy to the object itself.

At other times, however, the person–box system has settled into a relatively stable configuration, in which the kinematic pattern is somewhat independent of the major masses and pressures acting to shape posture. Walking with a box is one such example. The kinematic pattern could be frozen out and still the dynamics could be specified by posture because the entire body already has been shaped by the system dynamics, and this configuration will be at least partially independent of the kinematic pattern of bipedal locomotion. In the current study, the action phase of placing the box on the table, in addition to that of walking, contained informative static structure for the discrimination of box weight. Again, we would argue that posture has been shaped by the system dynamics. Although posture itself is being transformed in the process of moving the box onto the table, the slow and controlled manner of movement ensures a temporally close linkage between the weight of the box, the position of the box, and the actor's posture. For the activity under study at least, the effective static structures, although "frozen" in the photographic displays, are not themselves instantaneous but relatively persisting.

To conclude, our research has demonstrated that static depictions of movement, without added structures such as drawn motion lines or photographic streaks, sometimes are highly effective in specifying dynamics, and we have offered one line of reasoning on why some static views are especially effective. Naturally, there is much more experimental work to be done to test these ideas, and we have currently moved our efforts to (a) more precise measurement of structures of posture that could specify dynamics in these brief kinematic and matched instantaneous displays along the action path; (b) accurate measurement of the temporal lag between kinetic patterns (accelerations of masses) and postural consequences when actors manipulate various-sized loads; and (c) examination of the generality of the current findings relative to other activities and events.

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