it is brought to bear in the motor control of the action. A prototypical example of a scale error, and one of the original observations that sparked our interest in this topic, is a toddler attempting to sit on a miniature (dollhouse-size) chair. Other examples we have informally observed include young children trying to lie down in a doll's bed and attempting to get into a small toy car.

A scale error is defined as an attempt to perform an action that is totally impossible because of extreme differences in size – in this case, between a child's own body and a target object. When committing scale errors, children appear to be completely serious, with no indication of pretense or joking.

In our initial study designed to document the phenomenon of scale errors, children between 18 and 30 months of age were induced to play with three large toys in a laboratory playroom. They climbed up and slid down an indoor slide, sat in a child-sized chair, and got into and propelled a car around the room. Then, while the child was out of the room, each of the three large items was replaced by a miniature replica.

When they returned to the room, almost half of the children committed scale errors that were captured on camera. Some of them tried to climb up the stairs of the little slide, typically causing it to tip over. Others sat on top of the slide and attempted to go down it, often falling off in the process. Some of the children sat firmly down on the tiny chair, whereas others perched gingerly on top. Most remarkable of all, some children earnestly tried to get into the miniature car. After opening the car door, they attempted – sometimes quite persistently – to shove their foot in the small opening. The best way to appreciate the nature of these scale errors is to see them in action (which can be done by going to the following website: http://faculty.virginia.edu/childstudycenter/projects.html).

A particularly intriguing aspect of scale errors is that although the child's general plan is impossible because of the size of the target object, some of the movements that the child makes toward the object are accurately scaled. When trying to sit in a tiny chair, children typically check visually to see where the chair is, sometime even bending over and looking between their legs to locate it precisely. They then squat over it, lowering themselves to the point of contact. When trying to get into the miniature car, children first use fine motor control to open the car door. In addition, they sometimes hold on to the top of the car while trying to force their foot through the door, especially if their initial effort to get in has caused the car to skitter away.

It is this remarkable combination of wildly inaccurate and highly accurate behavior for which we find Glover's planning–control model to be particularly helpful. Interpreting scale errors in terms of his theory places their origin in the planning system. When a very young child encounters a miniature replica of a highly familiar type of object, visual processing of the replica activates the child's semantic representation of the larger object, or the class of objects, it stands for. Included in the activated memory representation of the full-sized object is the motor program or routine for interacting with it. Normally, visual processing of the size of the replica inhibits execution of the activated motor routine, and the child either does not attempt to act on the replica at all or carries out a very different action, such as pretense (for example, setting a doll in the miniature chair or pushing the car around on the floor making "vroom" sounds). Occasionally, however, for some reason an action plan is formed that does not take the available size information into account. Once the plan is initiated, the control system draws on the visual representation of size and adapts the child's movements to the actual size of the object. Thus, in the commission of a scale error, a child formulates an impossible plan but then employs finely controlled motor actions in the futile pursuit of it.

The application of Glover's theory to the scale error phenomenon extends it in three ways. First, in contrast to most of the research on which the model was originally formulated, here it is applied to full-body movements performed in large-scale space on real objects. Second, the planning–control dissociation is shown in the behavior of individuals, rather than by comparisons across participants. The same child fails to use size information in the process of formulating a fundamentally faulty plan, but does incorporate perceived size in the attempted execution of the plan. Third, applying Glover's planning–control model to the scale errors of very young children extends it to the developmental domain. Some developmental researchers have profitably applied the dual visual systems theory of Milner and Goodale (1995) to research on visually directed reaching in infants (e.g., Bertenthal 1996; Newman et al. 2001; Vishton 2003; Von Hofsten et al. 1998), and further valuable insights are likely to result from the consideration of early behavior in the light of the planning–control model.

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Visual context can influence on-line control

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Abstract: Several lines of evidence indicate that the on-line control of rapid target-aiming movements can be influenced by the visual context in which the movements are performed. Although this may result in movement error when an illusory context is introduced, there are many situations in which the control system must know about context in order to get the limb to the target rapidly and safely.

Beginning with the seminal work of Woodworth (1899), there is a long history of theorizing about the separate contribution of movement planning and on-line control processes to the regulation of goal-directed movement (see Elliott et al. [2001] for a recent review). However, Glover's planning and control formulation does have several features that make it a unique dual-process model of motor control. The most important of these features is the postulate that separate visual representations subserve movement preparation and on-line control. Although it is clear that different types of visual information are important for response selection, movement parameterization, and the rapid on-line modulation of movement, we are not convinced that the dichotomy described by Glover captures the flexible nature of on-line control. In this commentary, we review evidence from several aiming studies that indicates control processes can be sensitive to the visual context in which the aiming movement is performed.

In two of our recent experiments (cf. Meegan et al., in press), participants were required to aim a stylus from one vertex of Müller-Lyer figures to the other. In the first experiment, vision of both the limb and the figure was eliminated upon movement initiation, and in the second experiment participants were able to see their limb but not the figure during the movement. Regardless of whether there was a delay between elimination of the target figure and movement initiation, participants' aiming accuracy was biased by the Müller-Lyer configurations. Measures of displacement taken at peak velocity, at peak deceleration, and at the end of the movement indicated that the absolute magnitude of illusion-induced biases actually increased as the movement progressed. This was in spite of a dramatic trial-to-trial spatial variability decrease between peak deceleration and the end of the movement, indicating that participants were engaged in on-line control. These results are incompatible with both Glover's planning–control model, and Goodale and Milner's (1992) ventral-dorsal model.

In this same theoretical context, Proteau and Masson (1997) reported work that creates difficulty for the notion that the control system is uninfluenced by the visual environment surrounding the target. Their research involved participants making aiming move-

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ments to a stationary target embedded in a background that moved in either the same direction as the effector or in the opposite direction. These background perturbations, which were introduced at movement initiation, produced systematic overshooting and undershooting of the target respectively. Proteau and Masson postulated that when the background was moving in the same direction, the effector was judged to be moving more slowly than it really was and the movement was not terminated as soon as it should have been (i.e., a target overshoot). When the background was moving opposite to the direction of the movement, movement velocities were judged to be greater than they really were and the movement was terminated too early (i.e., target undershoot). Once again limb control appears to be susceptible to an illusory visual context. In a related study, Brenner and Smeets (1997) demonstrated that background motion introduced after planning affected the trajectory of manual aiming movements directed at foreground targets.

The notion that the control phase of an aiming movement is affected by visual context is consistent with aiming experiments in which the size-contrast illusion has been shown to influence movement time (e.g., van Donkelaar 1999). Although we agree with Glover that movement planning is partially responsible for the movement time-target size relation (e.g., peak velocity and the time to peak velocity), experiments in which target size changes on movement initiation (e.g., Heath et al. 1998) indicate that the time after peak velocity depends more on the target size after movement onset than the size of the target prior to the initiation of the movement. Moreover, the control system is able to adjust the temporal characteristics of the movement very rapidly in order to deal with target size perturbations.

While in some of the experiments described above, the visual surround contributed to either spatial error or temporal miscalculation, under many normal circumstances, visual context may prove to be important for efficient and safe on-line control. For example, when picking a berry from a thorny bush, or removing a steak from the grill, "good planning" may not always be enough to avoid an injury. The control system needs to take into consideration objects that surround the target or unexpectedly obstruct the path to the object once the movement is already underway. Certainly our ability to intercept a moving target depends partly on the expansion-contraction of the target's image on the retina relative to other objects. Similarly, the velocity of the effector used to intercept the target object will be judged relative to the visual environment in which it moves.

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Is there a dynamic illusion effect in the motor system?

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Abstract: Glover's planning–control model is based on his finding that visual illusions exert a larger effect in early phases than in late phases of a movement. But evidence for this dynamic illusion effect is weak, because: (a) it appears difficult to replicate; (b) Glover overestimates the accuracy of his results; and (c) he seems to underestimate the illusion effect at late phases.

Scott Glover draws a plausible picture of the visuo-motor system, such that we might be tempted to follow his arguments and believe in a planning–control model of action. However, Milner and Goodale (1995) also provided a plausible account of the visuo-motor system, as have other researchers (e.g., Livingstone & Hubel 1988; Schneider 1969; Trevarthen 1968; Ungerleider & Mishkin 1982). Logically, it seems unlikely that all these theories are correct. This necessitates a careful examination of the evidence used by the researchers. Here, I argue that Glover's most important evidence, the dynamic illusion effect, is weak. In fact, the dynamic illusion effect might not exist.

Glover and Dixon (2001a; 2001b; 2002a; 2002b) found that visual illusions exert a larger effect on early phases of a movement than on late phases. However, a careful examination of the studies shows that there are a number of problems related to this finding of a dynamic illusion effect. I will explain these problems using data from one of our studies (Franz et al. 2000), which I reanalyzed to test Glover's account (Franz 2003; submitted). In this study, participants repeatedly grasped objects of different sizes while perception of size was distorted by two different levels of the Ebbinghaus illusion. The aperture between the fingers was measured at different time points in the reach-to-grasp movements. The illusion effects are shown in Figure 1a. At first sight, the illusion seems to increase over time (instead of decrease, as suggested by Glover).

However, at early time points, the grasp aperture hardly responded to *any* variation in size, even if the physical size was varied (Fig. 1b). For an evaluation of the illusion effects, we have to take into account this smaller degree of responsiveness: We have to "correct" the illusion effects for the physical size effects. Only after this correction, can we detect a dynamic decrease of the illusion effect (if it exists).

In principle, the correction could be fairly easy: At each time point, we simply divide the illusion effect by the physical size effect (cf. Franz et al. 2001; Glover & Dixon 2001a). However, we also need to estimate confidence limits for the corrected illusion effects. This is not trivial, because we have to take into account the variability of the numerator and of the denominator. Consider the case where the confidence interval of the denominator contains a zero value. In this case, the corrected illusion effect can become arbitrarily large (or small), with arbitrarily large variability.

The method Glover and Dixon used to calculate confidence limits (or standard errors) for the corrected illusion effects ignores the variability of the denominator. This underestimates the variability of the corrected illusion effects. As I have discussed in detail (Franz, submitted), this problem can be most pronounced in early phases of the movement because here the physical size effect (i.e., the denominator) is close to zero.

Figure 1c demonstrates this problem for our data: Using Glover's method, one might be tempted to interpret the large corrected effect at $t = 0\%$ as evidence for a dynamic decrease of the illusion effect. The mathematically exact method (Fieller 1954; Franz, submitted), however, clearly shows that this value is a statistical outlier (Figure 1d): The confidence limits are *infinite*, because the physical size effect is too close to zero.

Figure 1d shows that (except for the outlier at $t = 0\%$), the corrected illusion effect is surprisingly constant, contrary to Glover's proposal. Now, it may be argued that these data have a drawback: Time points occurring after the maximum grip aperture (MGA) were not included in the analysis ($t = 100\%$ corresponds to the time of the MGA). However, the reason time points beyond the MGA were not included is because the fingers are already very close to the target after the MGA, and quite often will touch the target object, which would contaminate the data. But what if the dynamic illusion effect shows up only at time points after the MGA? To test for this, we reanalyzed the data of another study (Franz et al. 2003) and made sure that the trajectories were included as long as possible, but without the fingers touching the target object. Again, we found constant illusion effects over time, without any indication of a decrease. If at all, the corrected illusion effects slightly increased over time (Franz & Scharnowski 2003).

Why, then, did Glover and Dixon find a dynamic illusion effect? A close inspection of their results shows that the decrease of the corrected illusion effect occurs mainly at very late time points,

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