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Grasping without vision: Time normalizing grip aperture profiles yields spurious grip scaling to target size

Robert L. Whitwell [a,b], Melvyn A. Goodale [a,*]

[a] Department of Psychology, The Brain and Mind Institute, The University of Western Ontario, London, ON, Canada
[b] Graduate Program in Neuroscience, The University of Western Ontario, London, ON, Canada

A R T I C L E I N F O

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A B S T R A C T

The analysis of normalized movement trajectories is a popular and informative technique used in investigations of visuomotor control during goal-directed acts like reaching and grasping. This technique typically involves standardizing measures against the amplitude of some other variable – most typically time. Here, we show that this normalizing technique can lead to some surprising results. In the first of two experiments, we asked participants to grasp target objects without ever seeing them from trial to trial. In the second experiment, participants were given a brief preview of the target and were then cued 3 s later to pick it up while vision was prevented. Critically, on some trials during the delay period and unbeknownst to the participants, the previewed target was swapped for a new unseen one. The results of both experiments show that time-normalized measures of grip aperture during the closing phase of the movement appear to be scaled to target size well before the fingers make contact with the target – even though participants had no idea what the size of the target was that they were grasping. In contrast, a classical measure of anticipatory grip scaling, maximum grip aperture, did not show scaling to target size. As we demonstrate, however, in both experiments, movement time was longer for the larger target than the smaller ones. Thus, the comparisons of time-normalized grip aperture, particularly during the closing phase of the movements, were made across different points in real time. Taken together, the results of these experiments highlight a need for caution when investigators interpret differences in time-normalized dependent measures – particularly when the effect of interest is correlated with the dependent measure and a third variable (e.g., movement time) that is used to standardize the dependent measure.

1. Introduction

An informative and prolific line of research in motor control involves the study of goal-directed limb movements, such as reaching and grasping (see Culham & Valyear, 2006; Grafton, 2010; Jeannerod, 1999; Smeets & Brenner, 1999). Kinematic studies of these skilled movements typically involve large time-series data sets derived from repeated measurements of sensors attached to the hand and limb. In many cases the data are time-normalized to standardize the number of data points for each trial. Investigators do this to compare the normalized profiles of kinematic measures between or among conditions across the standardized 'bins' of, typically, time (e.g., Danckert, Sharif, Haffenden, Schiff, & Goodale, 2002; Dixon & Glover, 2009; Glover & Dixon, 2001a; Glover & Dixon, 2001b; Glover & Dixon, 2002a; Glover & Dixon, 2002b; Heath, Mulla, Holmes, & Smuskowitz, 2011; Heath & Rival, 2005; Himmelbach, Karnath, Perenin, Franz, & Stockmeier, 2006; Paulignan, Frak, Toni, & Jeannerod, 1997; Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991; Rand, Squire, & Stelmach, 2006; Whitwell, Lambert, & Goodale, 2008; Whitwell & Goodale 2009). Problems can arise, however, when measurements that are extracted from these normalized profiles are correlated with the variable used to standardize them in the first place. If grip aperture (which is typically scaled in flight for the size of the goal object) is measured at the same time bin in the normalized profiles for a series of grasps directed at goal objects of different sizes, a correlation between grip aperture and target size may simply reflect the fact that the duration of the movement is itself correlated with target size.

To illustrate this point, consider a typical grasping experiment in which participants are instructed to reach out and pick up targets of different sizes. We know that participants use vision to scale their grip aperture in flight to the size of the target presented on a particular trial (Jakobson & Goodale, 1991; Paulignan, Jeannerod et al., 1991; Whitwell and Goodale, 2009), and that participants can even do this in visual open-loop where they see

* Corresponding author. Tel.: +1 519 661 2070; fax: +1 519 661 3961.
E-mail address: mgoodale@uwo.ca (M.A. Goodale).

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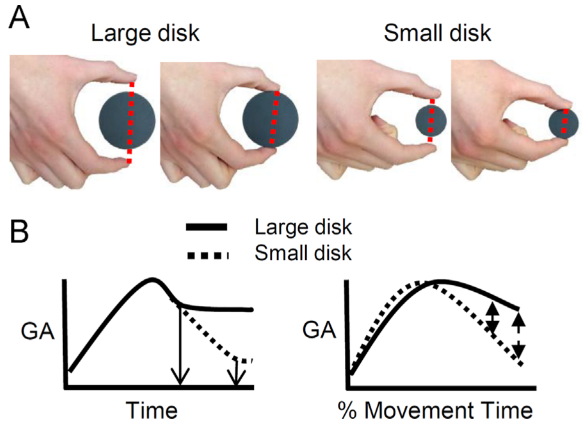

Fig. 1. Panel A: The thumb and pointer finger just prior to and at the moment of target contact. Despite the fact that the fingers have not made contact with the target, it is clear that the distance between them, grip aperture, will reflect the target's size. Panel B: Grip aperture profiles to large and small disks in raw time (left) and in normalized time (right). The downward-facing arrows in the raw time profiles (left graph) mark the time of contact with the target and the end of the movement. The raw grip aperture traces are identical apart from the fact that the trace for the smaller disk lasts longer and achieves smaller values. This occurs, of course, because the smaller disk leaves more room (and time) for the fingers to close down on and so the fingers take longer to make contact with it. Normalizing these data points to overall movement time introduces spurious grip scaling – differences (indicated by the double-headed arrows) in the opening of the hand that were never programmed.

the target at the outset but not during the execution of the movement (Jakobson & Goodale, 1991; Rand, Lemay, Squire, Shimansky, & Stelmach, 2007; Whitwell et al., 2008; Whitwell & Goodale, 2009). Now imagine a situation in which blindfolded participants reach out and grasp targets of different size. Common sense tells us that they would not show any grip scaling at all. Under these conditions, the participants would undoubtedly reach out tentatively, with a wide grip aperture to avoid fumbling as they grasped the smallest sized targets, and then close their hand down on the target. This would inevitably mean that their hand would take longer to make contact with the edges of a small target than it would for a larger one. In other words, the smaller the target, the longer the duration of the movement. If one were then to time-normalize the movements, a spurious relationship between grip aperture and target size would emerge in these profiles. For most of the movement the grasping movements for targets of different sizes, even in a time-normalized profile, would look quite similar, but as the hand closed down on the target, the time-normalized grasp for a smaller target would show a smaller grip aperture than the time-normalized grasp for the large target (see Fig. 1). In fact, the further along the time-normalized profiles, the more discrepant the difference in real time between these tentative blind grasps for small and large targets. To put it concretely, imagine that the movement time for a blind grasp towards a small target takes 500 ms while the same grasp directed towards a large target takes only 400 ms. At the beginning of the movement, around 10% of the way, the difference in real time would be only 10 ms. But by 90% of the way through, this difference in real time would have ballooned to a difference of 90 ms – creating a spurious difference in grip aperture for the two different targets. These and other systematic errors associated with normalized data of this kind can lead to erroneous conclusions about the operation of the underlying visuomotor networks.

In the present set of experiments, we looked at the effects of normalizing grasping data from blindfolded participants using a variant of task that has already been used to study on-line adjustments in grip scaling in a patient (IG) with bilateral lesions of the posterior parietal cortex (Himmelbach et al., 2006). In their experiment, the size of the target changed unexpectedly during the execution of a grasping movement. The authors reasoned that measures of grip aperture taken towards the end of a movement would more accurately reflect the contributions of any residual visuomotor ability to adjust the grasp than would measurements taken at the beginning of the movement (see also Glover, 2003, for a similar assumption regarding the relative contribution of movement planning and online motor control). Unfortunately, the authors based their assessment of IG's grip scaling on time-normalized measurements of grip aperture even though movement time was affected by target size. As a result, the apparent correlations they observed between grip aperture and target size at the end of the movements in IG, like those of the thought experiment described above, may simply have been a consequence of a comparison of grip aperture at two different points in time – points which would necessarily correlate with target size – rather than any residual ability to adjust the grasp for target size. To test this possibility, we examined the effects of normalization on 'blind' grasping in two experiments. In the first experiment, we asked blindfolded subjects to reach out and grasp targets of different sizes that they never saw. In the second experiment, we gave the subjects a preview of the target and then asked them to grasp it or a substitute while blindfolded. On some trials, the previewed target was swapped out for another of a different size during the delay period (see the "delayed real-grasping" task in Milner et al. (2001) for a similar protocol). Thus, although the target did not change during the movement, the movement itself was planned based on visual input and so the question was whether evidence for an adjustment to the unseen new target size would emerge in the normalized grip aperture as the response unfolded. We predicted that by normalizing the grip trajectories we would find 'evidence' for grip scaling and online adjustments in blindfolded participants, which of course should not be possible.

2. Experiment 1A

2.1. Methods

2.1.1. Participants

Ten self-reported right-handed individuals (M=31.4 years, SD= $\pm$ 8.8 years) provided their informed consent and were compensated $10 for their time.

2.1.2. Apparatus, procedure, and design

Participants were seated in front of a table with the tips of the thumb and pointer finger of their right hand pinched together resting on the start position (a small Felt disk). One infrared emitting diode (IRED) was attached the distal interphalangeal joint of the thumb and a second IRED was attached to the interphalangeal joint of the pointer finger. The positions of the IREDs were tracked for 2 s from the start of the trial using the CERTUS optoelectronic recording system (Northern Digital Inc., Waterloo, ON, Canada) at 400 Hz. For the practice and experimental trials, the participants wore PLATO goggles (Translucent Technologies, Toronto, ON, Canada) that were controlled by the experimenter and were used to occlude the participants' view of the workspace during the experimental trials. The lenses of these goggles default to a translucent state that blocks the wearer's view.

On a given trial, an auditory tone cued participants to reach out to pick up any one of four possible target disks using a precision pincer grasp with the thumb and pointer finger. The target disks were located 16 cm from the hand's starting position. To ensure that the position of the disks did not vary from trial to trial, each disk was positioned over a short peg that was fixed to the test table. Once the participant lifted the disk, he or she placed it back down on the table before returning to the starting position and resuming the starting hand posture. All four disks were 1.5 cm tall and varied only in terms of their diameter in increments of 8 mm. The smallest disk was 2.8 cm in diameter while the largest disk was 5.2 cm in diameter.

Critically, the lenses of the goggles remained in their default (i.e. view obstructing) state for both the practice and experimental trials. Thus, during the practice and experimental trials, the participants could not see the disks or the workspace and, therefore, had to rely on whatever memory of the disk's position that they had accrued. To minimize any tendency for participants' to probe for the target's position on each trial, the participants were instructed to contact the opposing sides of the disk with the thumb and pointer at the same time and to avoid leading their reaches with their pointer finger to find the target.