Peripheral Neuropathy and Length Perception by Dynamic Touch

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Dynamic touch is involved whenever an object is grasped and forces are imposed in order to move, stabilize, or carry it. Given its role in manipulating commonplace tools and utensils such as forks and hammers and coffee cups, dynamic touch can be considered critical to everyday function. A good deal of research suggests that time-invariant moments of the mass distribution of handheld objects, extracted by the nervous system during movement, constrain perception of object properties by dynamic touch. Nonvisual perception of object length, for example, is easily accomplished without practice or feedback and is constrained by the object’s resistance to being moved—quantified by its inertia tensor, $I_1$ (Fig. 1). One particularly robust finding is that the maximum principal moment of inertia $I_1$ is the primary constraint on muscle-based perception of the length of a wielded object.

The sensory disorder of peripheral neuropathy poses an interesting challenge for muscle-based perception. In extreme cases of the condition, individuals cannot feel anything touching their limbs, cannot feel anything their limbs are touching, and cannot feel the limbs themselves. Although full neuropathy is

![Figure 1.](attachment:image.png)

Figure 1. (a) The motions of a wielded object vary over time as do the torques used to produce the movements. (b) The inertia tensor couples the motions and torques, quantifying the resistance to being moved in different directions. (c) When the tensor is transformed relative to symmetry axes, the principal moments of inertia remain.
rare, partial neuropathy (typically affecting the extremities) is a fairly common consequence of aging and diabetes. Clearly, older adults and individuals with partial neuropathies continue to engage in behaviors that require them to manipulate objects. But to what extent is their everyday functioning compromised? Insight into this question was provided by an evaluation of dynamic touch in a patient with pronounced neuropathy in one arm.

**Method**

CA, a 40 year-old right-handed female, experienced complete insensitivity in the left arm, extending from the hand through the elbow with some involvement of the shoulder. The condition was due to a growth on the sensory tract at the top of the spine that was detected two months before testing. The loss of sensation was confirmed by a haptic identification task. Small 3-D numbers (approximately 2 cm × 2 cm × 1 cm) were placed in one hand singly, in random order. While blindfolded, she correctly identified every number immediately using the unaffected hand but none using the numb hand. (She declined to continue after dropping the first three, noting that she could not feel anything.)

Length perception by dynamic touch was evaluated using the typical methodology (Fig. 2a). Wooden dowels were cut into three sets of three lengths (L = 45, 60, and 80 cm). In order to manipulate $I_c$, one member of each length set was presented with a metal disk at $1/3$ L, one with the disk at $2/3$ L, and one without a disk. Each of the nine rod configurations was presented three times in random

![Figure 2](image-url)

*Figure 2.* (a) When rods were wielded by the numb hand, the intact hand adjusted a marker to indicate felt length. (b) CA was unable to control the pulley system with her numb hand. Therefore, when the rods were wielded by the unaffected hand, she instructed the experimenter where to place the marker to indicate felt length.
order. Perceived length was evaluated for the numb hand in the first block of 27 trials and for the intact hand in the second block of 27 trials. (CA wielded the rods in the affected hand without objection. She could not use that hand to grip the string of the report apparatus, however, so the experimenter made the back-and-forth adjustments for her; Fig. 2b.)

**Results and Discussion**

Standard findings for these kinds of experiments were replicated: Perceived length increased with rod length; rods with attached masses were felt to be longer than rods without attached masses; and perceived length increased the farther the attached disk was from the hand. All of these reflect the influence of the maximum principal moment of inertia \( I_1 \) on perceived length. In particular, the \( 1/3 \) scaling of log perceived length on log \( I_1 \) emerged—the slope of the regression was .35 for both the intact and the numb hand.

A Discrimination Index was used to evaluate whether the two hands were comparable in discriminating the rods:

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DI = a/s.d.
\]

where \( a \) is the slope of the regression of perceived length on actual length. \( DI = 5.5 \) for the intact hand and 5.8 for the numb hand. These numbers are comparable to those found for the right (5.7) and left hands (5.9) of right-handers without neuropathy (Carello et al., 2002).

A difference between the two hands was found with respect to the intercept of the regressions, indicating that perceived length using the numb hand was considerably shorter than perceived length using the intact hand (Fig. 3a). For rods whose actual lengths varied from 45–80 cm, perceived lengths varied from

![Figure 3. Regressions of perceived length on the maximum principal moment of inertia \( (I_1) \) in log-log coordinates. (a) The functions for the affected and unaffected hands of a right-handed woman with unilateral neuropathy are parallel but with distinct intercepts. (b) Comparable functions for the right and left hands of normal right-handers show the same slope and a single intercept.](image-url)
For normal right-handers, in contrast, neither the slopes nor the intercepts of the two regressions differed, $p > .50$ (Fig 3b). The latter result indicates that the shorter perceived lengths associated with CA’s numb hand were not simply a consequence of being wielded by the non-dominant hand.

How is CA able to perceive length at all with such severely compromised neuromuscular contact? More pointedly, given that the scaling to $I_1$ is appropriate, why are perceived lengths in a shorter range? For insight, we appeal to experiments in which tissue contact with a target rod is varied. Perceived rod length is comparable whether a rod is grasped in one hand or contact is distributed over two hands, one hand and one knee (Carello et al., 1992), or even supported by an axle at one end and lifted with a probe rod at the other end (Peck et al., 1996). In all cases, perceived length is constrained by rotational dynamics. Most notably, shorter perceived lengths accompany a wider separation between rod supports, a manipulation has the effect of reducing the resistance to rotation (Carello et al., 1992). The success of the insensate limb suggests that the subsystem of dynamic touch can exploit the field-like structure of the mechanoreceptor support for haptic perception—wielding an object deforms the tissues of the body not just of the hand. The reduced magnitudes arise because the proximal field structure is reduced where the deformation is registered (presumably, at or beyond the shoulder). Thus, the detection of invariants revealed through movement is a major mechanism in kinesthetic perception involving intact limbs, neuropathic or anesthetized limbs, prosthetic devices, and hand-held-tools and implements (Pagano & Turvey, 1998).

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References


