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Carpal tunnel syndrome impairs sustained precision pinch performance

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HIGHLIGHTS

- Sensorimotor deficits associated with carpal tunnel syndrome (CTS) lead to reduced accuracy and stability in digit force control for precision pinch.
- Visual force feedback compensates for force production errors associated with CTS.
- CTS did not affect the structure of force variability or force correlation between digits.

ABSTRACT

Objective: The purpose of this study was to investigate effects of carpal tunnel syndrome (CTS) on digit force control during a sustained precision pinch.
Methods: Eleven CTS individuals and 11 age- and gender-matched healthy volunteers participated in the study. The subjects were instructed to isometrically pinch an instrumented apparatus for 60 s with a stable force output. Visual feedback of force output was provided for the first 30 s but removed for the remaining 30 s. Pinch forces were examined for accuracy, variability, and inter-digit correlation.
Results: CTS led to a decrease in force accuracy and an increase in amount of force variability, particularly without visual feedback ($p < 0.001$). However, CTS did not affect the structure of force variability or force correlation between digits ($p > 0.05$). The force of the thumb was less accurate and more variable than that of the index finger for both the CTS and healthy groups ($p < 0.001$).
Conclusions: Sensorimotor deficits associated with CTS lead to inaccurate and unstable digit forces during sustained precision pinch.
Significance: This study shed light on basic and pathophysiological mechanisms of fine motor control and aids in development of new strategies for diagnosis and evaluation of CTS.

1. Introduction

Carpal tunnel syndrome (CTS) is the most common peripheral entrapment neuropathy caused by chronic compression of the median nerve. The median nerve innervates some intrinsic muscles in the hand and relays sensory information from the palmar aspect of the thumb, the index and middle fingers, and the lateral half of the ring finger. Prolonged compression on the nerve in the carpal tunnel leads to sensory symptoms such as paresthesia (tingling, burning and itching), numbness and pain, as well as motor symptoms such as stiffness, clumsiness and weakness of the hands (Rosenbaum and Ochoa, 2002). These sensory and motor deficits impair hand functions for manual activities of daily living such as buttoning of clothes, holding a book while reading, and gripping of a telephone handset (Levine et al., 1993), which require well controlled digit forces. Understanding of the effects of CTS on digit force control extends and complements the existing clinical tools to diagnose and evaluate CTS (Arendt-Nielsen et al., 2004).

Previous studies on digit force control due to peripheral median neuropathy have resulted in inconsistent findings. In two-digit precision grip performed with the thumb and index finger, CTS patients exerted greater grip force than healthy subjects when holding a tool (Lowe and Freivalds, 1999). Increased grip force magnitudes were also observed in several simulated peripheral neuropathy studies via mechanical compression of the median nerve at the wrist (Cole et al., 2003), anesthetic injection to the

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carpal tunnel to block the median nerve (Dun et al., 2007), and local anesthesia of the digital nerves (Augurelle et al., 2003). In contrast, conflicting findings were also reported that both CTS individuals and the healthy controls had similar grip force and grip-to-load force ratio with whole hand gripping (Nowak et al., 2003), generated similar extent of compensatory moment for a full hand grasping (Zhang et al., 2012), and equivalently modulated the grip force in relation to friction during two-digit gripping (Thonnard et al., 1999). The effects of CTS on grasping function can be influenced by a number of factors such as task specifications (e.g. vertical lifting, horizontal moving or static holding), number of digits engaged in grasping, nerve impairment conditions, and available sensory modalities (e.g. grasping under visual (Zhang et al., 2012) or non-visual guidance (Dun et al., 2007)).

Among many manual functions, precision pinch using the thumb and index finger is a common daily manual task, and an effective, reliable, and easy to perform testing paradigm. During a precision pinch, the thumb and index finger intricately coordinate with each other to apply proper amount of force (Gordon et al., 1991; Li and Li, 2013; Marquardt and Li, 2013; Nowak and Hermsdorfer, 2002; Westling and Johansson, 1984). Because CTS prominently impairs the sensory and motor function of the thumb and index finger, the seemingly effortless task of precision pinch for an intact hand may pose challenges to patients with CTS. For example, a CTS patient may show difficulty in coordinating the thumb and index finger for precision pinch forces and movements. Pathomechanics during precision pinch could reveal underlying sensorimotor deficit associated with CTS.

Applying digit force during precision pinch involves a complex sensorimotor process. The somatosensory system, including the tactile sensation and proprioception, plays a crucial role in digit force control (Nowak and Hermsdorfer, 2005; Rothwell et al., 1982). Visual cues supply information about the object's property for anticipatory force control (Jenmalm, 1997). During prolonged isometric contraction, visual feedback of force production in comparison with target force improves the force accuracy and stability (Baweja et al., 2009; Jordan and Newell, 2004), and modulates inter-digit force coordination (Li et al., 2013a). The uncertainty of one sensory modality results in increased dependency on other afferent information (Calvert et al., 2004), and individuals with CTS who have impaired hand sensorimotor function could increasingly rely on visual feedback to maximize task performance. However, the extent to which CTS affects digit force control with and without visual feedback remains to be understood.

The current study aimed to examine the effects of CTS on force accuracy, variability, and inter-digit force coordination during sustained precision pinch with and without visual feedback. We hypothesized that CTS subjects, compared to the healthy controls, would perform precision pinch with lower force accuracy, higher force variability and reduced inter-digit force coordination, particularly under the condition without visual feedback.

2. Methods

2.1. Subjects

Eleven CTS patients and 11 age- and gender-matched healthy volunteers participated in this study. All participants gave their written informed consent according to the protocols approved by the Institutional Review Board. The subject characteristics are shown in Table 1.

Inclusion criteria for both CTS and healthy subjects were: (1) age 21–70 years old, (2) right-hand dominance verified by Edinburgh Handedness Inventory (Oldfield, 1971), and (3) normal or correct-to-normal vision. The CTS subjects received a clinical diagnosis of CTS in the right hand (Keith et al., 2009) which was supported by satisfying at least three of the following criteria: (a) history of parathesias, pain, and/or numbness in the median innervated hand territory persisting for at least 3 months; (b) positive provocative maneuvers (Tinel's sign, Phalen's test, and/or median nerve compression test); (c) abnormal electrodiagnostic testing consistent with median nerve neuropathy at/or distal to the wrist (sensory latency > 3.7 ms and/or motor latency > 4.6 ms) (Stevens et al., 1999); and (d) an overall CTS Severity Questionnaire score of greater than 1.5 (Levine et al., 1993). For the control group, the inclusion criteria were (1) gender- and age-matched to a CTS subject within ±5 years and (2) no history of disease, injury, or previous complications involving the hand and upper extremity. The exclusion criteria for CTS and control subjects included: (1) ulnar,

Table 1
Characteristics of the CTS and healthy subjects.

Num total	CTS										Control				
	Sex	Age (y)	Maximal pinch force (N)	SWM score (1)	MHQ score (2)	LSQ score (3)	Motor		Sensory		Age (y)	Maximal pinch force (N)	SWM score	MHQ score	LSQ score
							Latency (ms)	CMAP (mV) (4)	Latency (ms)	SNAP (uV) (5)					
1	F	35	35.3	3.61/3.84	50.7	51	5.1	8.7	2.7	22.7	35	59.5	2.44/1.65	83.3	20
2	M	51	100.0	2.83/2.83	37.9	74	6.3	9	6	11.4	55	77.8	2.83/2.44	83.3	19
3	F	52	48.7	3.22/2.44	49.0	52	5.2	8	4.4	15	47	52.3	3.22/2.83	83.3	19
4	F	43	52.3	3.22/3.22	26.2	80	3.85	3.91	3	34.6	43	44.1	2.44/2.44	80.8	20
5	F	35	54.2	2.44/2.44	44.7	57	NA	NA	3.2	32.6	34	70.3	1.65/2.36	83.3	19
6	F	53	44.8	2.83/2.44	40.7	63	6.1	1.6	3.9	10.3	56	51.0	2.36/2.44	96.25	23
7	F	51	45.8	3.22/3.22	65.9	41	5	5.23	2.25	39.1	49	60.4	2.83/2.44	81.5	20
8	F	46	45.1	3.22/3.22	53.5	62	3	11.6	2.9	29.1	48	56.2	2.44/2.44	83.3	19
9	F	64	38.9	3.22/3.22	74.4	42	2.9	7.6	3.2	24.7	60	46.1	2.83/2.44	83.3	19
10	F	52	41.2	3.61/2.83	66.4	60	5.55	3.82	7.2	11.9	53	56.2	2.44/2.83	82.3	21
11	M	64	67.3	3.84/3.22	57.0	56	6.8	4.6	NA	NA	57	84.0	2.83/2.83	83.33	19
Mean		49.6	52.1	3.21/2.99	51.5	58	4.98	6.406	3.88	23.14	48.8	59.81	2.57/2.47	84.00	19.8
SD		9.6	18.1	0.40/0.44	14.1	11.9	1.34	3.05	1.58	10.59	8.6	12.70	0.41/0.33	4.16/0.328423	1.3

(1) SWM = Semmes Weinstein Monofilament. Scores were presented as thumb/index finger.
(2) MHQ = Michigan hand outcomes questionnaire.
(3) LSQ = Levine's severity questionnaire. Data presented were the total score.
(4) CMAP = Compound motion action potential.
(5) SNAP = Sensory nerve action potential.