Neuropsychologia 59 (2014) 142–147

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Eating tools in hand activate the brain systems for eating action: A transcranial magnetic stimulation study

Kaori Yamaguchi [a,*], Kimihiro Nakamura [a,b], Tatsuhide Oga [c], Yasoichi Nakajima [a]

[a] National Rehabilitation Center for Persons with Disabilities, Research Institute, 4-1 Namiki, Tokorozawa 359-8555, Japan
[b] Human Brain Research Center, Kyoto University Graduate School of Medicine, 54 Shogoin, Kyoto 606-8507, Japan
[c] Toranomon Hospital Kajigaya Department of Rehabilitation, 1-3-1 Kajigaya, Takatsu-ku, Kawasaki, Kanagawa 213-8587, Japan

ARTICLE INFO

Article history:
Received 26 December 2013
Received in revised form
19 April 2014
Accepted 4 May 2014
Available online 13 May 2014

Keywords:
Eating action
Masseter muscles
Motor-evoked potential (MEP)
Sensorimotor
Transcranial magnetic stimulation (TMS)

ABSTRACT

There is increasing neuroimaging evidence suggesting that visually presented tools automatically activate the human sensorimotor system coding learned motor actions relevant to the visual stimuli. Such crossmodal activation may reflect a general functional property of the human motor memory and thus can be operating in other, non-limb effector organs, such as the orofacial system involved in eating. In the present study, we predicted that somatosensory signals produced by eating tools in hand covertly activate the neuromuscular systems involved in eating action. In Experiments 1 and 2, we measured motor evoked response (MEP) of the masseter muscle in normal humans to examine the possible impact of tools in hand (chopsticks and scissors) on the neuromuscular systems during the observation of food stimuli. We found that eating tools (chopsticks) enhanced the masseter MEPs more greatly than other tools (scissors) during the visual recognition of food, although this covert change in motor excitability was not detectable at the behavioral level. In Experiment 3, we further observed that chopsticks overall increased MEPs more greatly than scissors and this tool-driven increase of MEPs was greater when participants viewed food stimuli than when they viewed non-food stimuli. A joint analysis of the three experiments confirmed a significant impact of eating tools on the masseter MEPs during food recognition. Taken together, these results suggest that eating tools in hand exert a category-specific impact on the neuromuscular system for eating.

1. Introduction

Eating is the most fundamental biological requirement for all living organisms. For humans, in particular, eating is not a simple neuromuscular process but a more complex, learned behavior sensitive to other psychophysical and socio-cultural factors. Indeed, human eating behavior has been studied extensively in variously different disciplines of social, psychological and biomedical sciences. In the medical literature, for instance, most previous studies on eating have focused on the disease prevention and dietary intervention for cardiovascular and metabolic disorders (Clark et al., 2004; Eriksson et al., 2006; Eertmans et al., 2001), end-stage illness such as cancer and dementia (Manthorpe & Watson, 2003; Palecek et al., 2010) and bulimia or anorexia nervosa (Kaye, 2008; Schebendach et al., 2008). Recent neuroscience research has further shed light on neuroanatomical underpinnings of eating behavior, including the frontal insula-operculum and orbitofrontal regions involved in gustatory semantics (Simmons, Martin & Barsalou, 2005; Barrós-Loscertales et al., 2012) and the hypothalamic region involved in food intake (Berthoud, 2002) and reward seeking (Harris, Wimmer & Aston-Jones, 2005).

For humans, however, eating action is also a more complex sensorimotor process which relies on a skilled control of eating tools (e.g. forks and knives). That is, the typical act of eating in humans consists of a learned sequence of visuomotor processing, including the visual recognition of food, motoric control of eating tools and coordinated movements of cranial and pharyngeal muscles for mastication and swallowing. Notably, however, despite the large number of previous biomedical studies on eating, remarkably little is known about this neuromuscular mechanism involved in eating action. Given the fact that such complex coordinated sequence of visual and motor systems is generally acquired in early stages of life and habitually utilized across lifespan, it is likely that normal humans should have a strongly interconnected neuromuscular circuit involved in eating action (Cattaneo et al., 2007).

Indeed, several lines of behavioral and neuropsychological evidence suggests that somatosensory stimulation induced by tools in hand activates the human motor system coding relevant actions. For instance, a behavioral study with "apraxic" patients

* Corresponding author. Tel.: +81 4 2995 3100.
E-mail address: yamaguchi-kaori@rehab.go.jp (K. Yamaguchi).

http://dx.doi.org/10.1016/j.neuropsychologia.2014.05.003
0028-3932/

has shown that motor planning dysfunction can be ameliorated when these patients hold real tools in hand (Goldenberg, Hentze & Hermsdorfer, 2004). Similarly, clinical observations of severely demented patients with eating difficulty suggest that eating utensils in hand can facilitate voluntary eating action (Osborn & Marshall, 1993). These observations may generally concur with the well-known theory of "affordance", whereby the implicit physical attributes of perceived objects constrain and interact with the observer's motor action and its planning (Derbyshire, Ellis & Tucker, 2006; Ranganathan, Lee, Brown & Newell, 2011; Sartori, Straulino & Castiello, 2011).

At the neural level, many previous studies suggest that the visual observation of tools activates the frontoparietal regions storing the semantic and action-related knowledge of skilled tool use (Johnson-Frey, 2004; Vingerhoets, 2008; Chao et al., 1999; Beauchamp et al., 2002; Martin et al., 1996). Such cross-modal activation may reflect a general functional property of the human motor system, because the similar activation of learned motor memory is known to be triggered by external stimuli in various other modalities, including written numerals (Sato, Cattaneo, Rizzolatti & Gallese, 2007), musical sounds (Haueisen & Knosche, 2001) and flavor (Parma, Ghirardello, Tirindelli & Castiello, 2011a; Parma et al., 2011b). In particular, food-related sensory stimuli can also exert a cross-modal effect on the motor system, since it has been shown that sniffing alimentary odorants increases the motor excitability of hand muscles during the observation of grasped food (Rossi et al., 2008). It is therefore possible that somatosensory stimulation from eating tools can covertly activate the neuromuscular systems involved in eating action. To our knowledge, however, no previous work has examined the hypothesized link between the human neuromuscular system and eating tools.

In the present study, we tested this prediction using transcranial magnetic stimulation (TMS) in healthy humans. Specifically, we hypothesized that eating tools in hand should activate the neuromuscular system involved in eating action during the visual observation of food stimuli. We first examined whether tactile stimulation by eating tools can modulate motor evoked potentials (MEPs) from jaw muscles (masseter, see Section 2) while participants made semantic judgment about edible objects (Experiments 1 and 2). We observed that the masseter MEPs increased more greatly when participants held eating tools than when they held other hand-operated tools in their dominant hand. In Experiment 3, we further included food and non-food objects as visual stimuli to assess whether this modulatory effect by eating tools is specific to edible objects or rather it is generalized to other, non-edible objects. We confirmed that chopsticks overall increased MEPs more greatly than scissors and this tool-driven increase of MEPs was greater when participants viewed food stimuli than when they viewed non-food stimuli. Therefore, the observed increase in the motor excitability of the jaw muscles relies not on the direct motor activation by tactile input, but on the integrated long-distance signals via the visual object recognition system and hand sensorimotor system.

2. Material and methods

2.1. Participants

A total of 36 native Japanese students (age range 23–28 years) participated in the present study (3 males and 9 females for Experiment 1, 4 males and 8 females for Experiment 2, and 3 males and 9 females for Experiment 3). All were right-handed on the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. All of them habitually used chopsticks with their right hand and were on fasting for at least 1 h prior to the experiment. None had either a history of neurological or psychiatric disorders or any other contraindication to TMS (Wassermann, 1998; Rossi, Hallett, Rossini & Pascual-Leone, 2009). Written informed consent was obtained from all participants prior to commencing the study in a manner approved by the institutional ethical committee.

2.2. Behavioral paradigm

All behavioral paradigms were programmed using E-prime software (Psychology Software Tools, USA). For Experiment 1, we used a semantic categorization task with visually presented food stimuli. Stimulus materials included 100 color photographs of food, half representing hot food (e.g. noodles, fried chicken) and the other half cold or room-temperature food (e.g. salad, sushi). Normal Japanese adults can easily use chopsticks when eating these food items. Each trial consisted of a sequence of central fixation (1500 ms) and a target on the center of the screen (600 ms, Fig. 1A). Participants responded by key-press, either with their left index finger when target pictures represented hot food or with their left middle finger when otherwise.

The experimental session consisted of eight blocks of 25 trials (total 200 trials). In each block lasting ~75 s, participants held either chopsticks or scissors in their

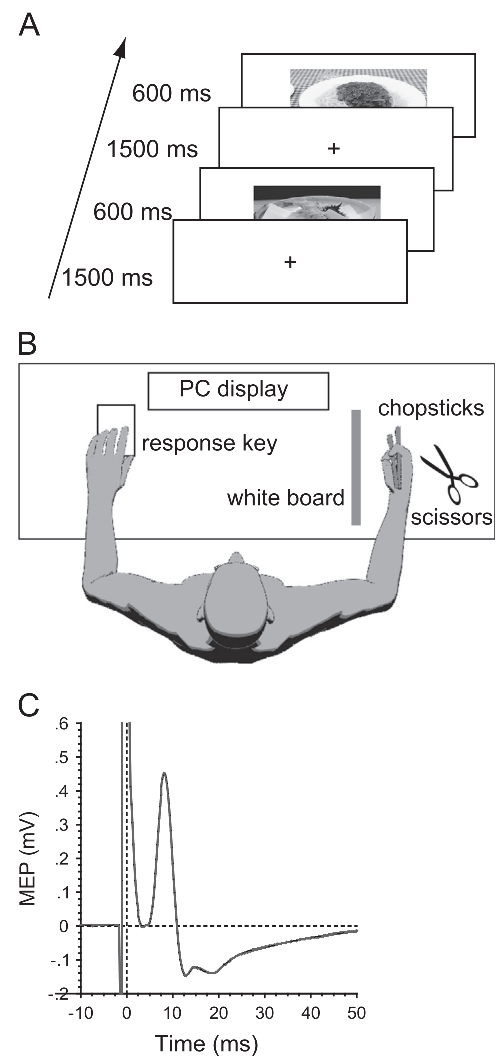

Fig. 1. Behavioral paradigm. (A) Sequence of stimuli. Each trial consisted of central fixation (1500 ms) and a picture of food (600 ms) presented on the center of the screen. Participants made semantic judgment about food stimuli in Experiment 1 (hot vs. cold) and Experiment 2 (sweet vs. non-sweet) and oddball detection of non-food targets in Experiment 3 (see Section 2 for detail). (B) Experimental set-up. Participants are seated facing a PC monitor and responded to visual stimuli by key-press with their left fingers while holding either chopsticks or scissors in their right hand. Participants are unable to see the tools in their right hand placed behind a 40 × 30 cm^2 blank white board throughout the experimental session. In each trial, a single-pulse TMS synchronized with the onset of visual targets is delivered to the face area of the left motor cortex. (C) Overall waveform of the masseter MEPs averaged across participants in Experiment 1. The overall magnitude (~3 mV) and latency (~7 ms) of the observed MEPs are highly compatible with the previously known pattern of the masseter MEPs (Guggisberg et al., 2001; Pearce et al., 2003; Jaberzadeh et al., 2008).