Available online at www.sciencedirect.com
ScienceDirect
Neurocomputing 71 (2007) 411–416
NEUROCOMPUTING
www.elsevier.com/locate/neucom

Letters

Neural modelling of hand grip formation during reach to grasp

J. Molina-Vilaplana*, J. López-Coronado

Department of Systems Engineering and Automation, Technical University of Cartagena, Campus Muralla del Mar s/n, E-30.202 Cartagena, Murcia, Spain

Received 22 November 2006; received in revised form 21 February 2007; accepted 13 August 2007
Communicated by L.C. Jain
Available online 7 September 2007

Abstract

We investigate the spatio-temporal dynamics of hand preshaping during prehension through a biologically plausible neural model. The hand grip formation is generated through neural modulation of basic motor programs that can be rescaled to accommodate different task demands. The model assumes a timing role to propioceptive reafferent information generated by the reaching component of the movement, avoiding the need of a preorganized functional temporal structure for the timing of prehension as some previous models have proposed. Predictions of the model in both Normal and Altered initial hand aperture conditions match key kinematic features present in human data.

Keywords: Human prehension movements; Computational neural models; Motor control

1. Introduction

To grasp an object, the central nervous system (CNS) must program two simultaneous motor actions: hand transport to the location of the object to be grasped and hand preshaping to enclose object [5,16]. There is a parallel evolution of reaching and hand preshaping processes, both of them initiating and finishing nearly simultaneously. The time of maximum grip aperture is well correlated with the time of maximum deceleration of the transport component [5]. According to [1] and [6]; the transport and hand preshaping components evolve independently through two segregated visuomotor channels, coordinated through a central preorganized functional temporal structure. This mechanism should ensure the temporal alignment of key moments in the evolution of the two components: in this way, Jeannerod [6] suggested that this central timing mechanism operates such that peak hand aperture is reached at the moment of peak deceleration of the reaching component.

Several studies have demonstrated a peculiar effect of initial hand aperture on the grip formation in reach to grasp movements. In [11] and [17] is reported that for precision grip movements starting with an initial finger aperture, the hand aperture closed and then reopened before maximum grip aperture was achieved. This was remarkable as it was expected a monotonic closing of the hand towards the object. Recently, predictions of two different models [7,14] for prehension have been compared with the findings mentioned above [15]. These two models can account for many aspects of human grasping when the movement starts with the digits in contact. However, both models predict an initial hand opening in the Altered initial hand aperture condition that is not present in the human data.

In this communication we investigate the spatio-temporal dynamics of hand preshaping in Normal and Altered conditions using vector integration to endpoint (VITE) [2] dynamics. The model proposes that the hand preshaping dynamics during prehension emerges from the combined action of the feedforward motor program execution and the temporal coordinative role of proprioceptive reafferent information related with the transport phase of the movement.

2. Methods and algorithms

The preshaping and reaching components have been simulated using the VITE model (Fig. 1) [2] which

*Corresponding author. Tel.: +34 968 32 53 59.
E-mail address: javi.molina@upct.es (J. Molina-Vilaplana).

0925-2312/$ - see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.neucom.2007.08.017

postulates that voluntary movement trajectories emerge as internal gating signals generated at subcortical centres, control the integration of continuously computed vector commands based on the evolving, perceptible difference between desired and actual position variables. VITE model does not propose any adaptive learning procedure for acquisition of movement skills, it only constitutes a simple dynamical system that describes a plausible biological mechanism able to explain several properties of human reach to grasp movements such as the asymmetric bell-shaped velocity profiles and the speed-accuracy trade-off law. A huge biological background for the model can be found in [2].

The hand aperture is modeled as one degree of freedom (DOF) system. This corresponds to modeling the distance (aperture) between thumb and index finger directly. Computationally speaking, the VITE system gradually integrates the difference between the desired target finger aperture (T_A) and the actual finger aperture (P_A) to obtain a difference vector (D_A). The difference vector codes information about the amplitude and direction of the desired movement, and its is modulated by a time-varying *GO* signal to produce a desired finger aperture velocity ($V_A = D_A \cdot G(t)$). The outflow command (V_A) is integrated to update the finger aperture (P_A) as shown in Eqs. (1)–(3).

$$\frac{dD_A}{dt} = \eta \cdot (-D_A + T_A - P_A), \tag{1}$$

$$\frac{dP_A}{dt} = G(t) \cdot D_A, \tag{2}$$

$$G(t) = GO \cdot \frac{t^2}{(0.25 + t^2)}, \tag{3}$$

where *GO* is the gain for the gating signal $G(t)$ and η is a rate of integration. It is proposed that the movement preshaping of hand and fingers in prehension can be understood in terms of basic motor programs and that the neural representation for these motor programs evolves gradually over time [3,8,12]. The motor program for the grasp component was modeled as a biphasic motor program consisting of two successive subprograms (G_{A1}, G_{A2}), where G_{A1} is related to the maximum grip aperture and G_{A2} equals the object size. It is hypothesized that the intrinsic properties of the object such as object size may be computed in advance of the onset, whereas the acquisition of the target grip aperture may evolve even after aperture onset. The model assumes that the target aperture is not fully programmed in T_A before movement initiation [10]; rather, it is postulated that T_A in grasp channel, sequentially and gradually specify, in a first phase the desired maximum grip aperture (G_{A1}), and in a second phase, the hand configuration corresponding to the object size (G_{A2}). We have modified the VITE model to account for this gradual specification of target grip amplitude. The proposed modification in T dynamics of grasp channel is described by Eq. (4),

$$\frac{dT_A}{dt} = \beta(-T_A + G_{A(i)}), \tag{4}$$

where β is a rate of integration and $i = 1, 2$.

In the case of the transport component, classical VITE dynamics has been used to simulate the wrist position evolution through movement. A single and constant over time input, fully specified the target distance T_T. Simoneau and collaborators [13], have suggested that during a unimanual reach to grasp task, proprioceptive reafferents are used to coordinate transport and grasp motor program execution by the two related neural channels. These authors concluded that reafferent proprioceptive information from the reaching movement is used by the CNS to coordinate the reaching and grasping movements. In the model, we have adopted this hypothesis and, the detection of a minimum in transport acceleration by the C_p neuron (which continuously monitors velocity and acceleration in transport channel) triggers the read-in of G_{A2} (e.g., C_p

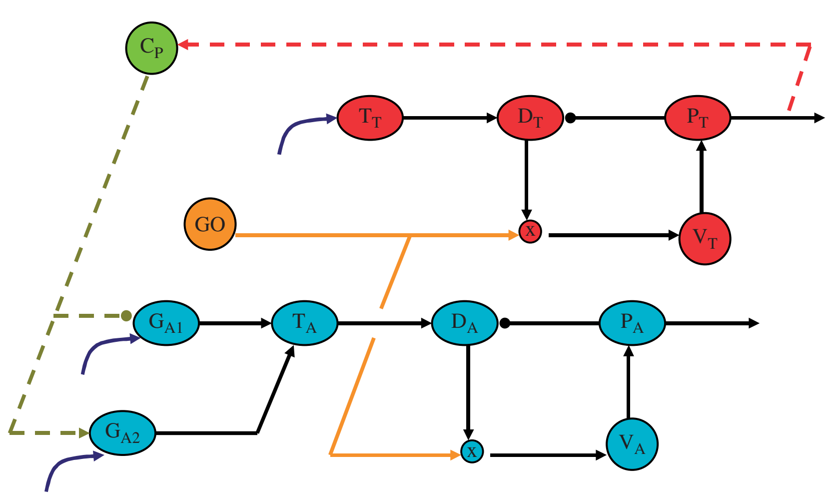

Fig. 1. Neural network model for hand grip formation. Visuomotor channels involved in transport (T sub index) and grasp (A sub index) phases of the movement are modeled using VITE model. Inhibitory connections are represented as lines finishing in a circle. Excitatory connections are represented as an open arrow. Multiplicative gating connections arise from *GO* signal generator and modulate outflow motor command (P_A and P_T) updating.