Vibrotactile movement initiation

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Abstract. We investigated how to use vibrotactile stimuli to initiate limb movements, in particular wrist rotations. We compared stimulation of the to be activated muscle with specification of the direction to which that particular part of the body had to be moved (i.e., the use of an intrinsic or an extrinsic reference frame for motor control). Fifteen participants took part in an experiment in which five stimulus locations on the arm were compared on reaction times for left and right wrist rotations. We concluded that an extrinsic reference frame should be used for specifying wrist rotations using vibrotactile stimuli: The vibrotactile stimulus should be presented at the side of the hand that corresponds with the direction where the hand should move to.

1 Introduction

Several studies have indicated that vibrotactile displays can support navigation while walking [1], or while operating a car [2], a helicopter, or a speedboat [3]. These displays consist of arrays of tactile actuators, attached to the body, that communicate information by vibrating at a specific location. In addition to the actuators, systems like GPS and a compass are required to monitor one's position and orientation. The most simple set-up is where only one actuator vibrates: the one that is attached to that side of the body that corresponds with the desired direction of movement. This 'follow-the-needle' principle has proven to be very intuitive. In the study presented here, we investigated whether we can use vibrotactile displays not only to communicate *where* to move to, but also *how* to move. In other words, can we use vibrotactile stimuli to tell someone what muscles to contract or what joints to rotate, and at what moment, in order to establish the required movement? If that indeed is possible, vibrotactile displays could be used in learning new co-ordination patterns in movement, like walking with a lower limb prothesis, or learning how to control an aeroplane. Another application is to fine-tune already existing co-ordination patterns by providing real-time feedback on the difference between the actual and required movement while one is performing the task, as in bringing the golf swing to perfection.

To investigate whether vibrotactile displays can indeed tell someone in an intuitive way how to move, we focussed on a simple task: rotating the wrist either to the left, or to the right. We seek to find a general principle of intuitively coding vibrotactile information for movement initiation that can also be used in more complex task settings like the ones mentioned above.

1.1 Intrinsic or extrinsic coding for vibrotactile movement initiation

The candidate principles we investigated are based on studies in motor control. Traditionally, two kinds of models on motor control can be distinguished. Models based on extrinsic frames of reference assume that movements are planned and co-ordinated using the external world as a reference (e.g., [4]) According to these models, the most efficient way to move a hand from one location to another is along a straight line through the external world. Translated to our application, the vibrotactile stimulus should then be presented at the hand, indicating the direction of wrist rotation with respect to the external world. Models based on intrinsic frames of reference, on the other hand, assume that movement planning and co-ordination is conducted with respect to body co-ordinates, like muscle torque to be generated or joint angles to be adopted (e.g., [5] [6]). Transportation of the hand would then be most efficient along a straight line within this intrinsic frame of reference (defined by joint angles, muscle torque, …), possibly leading to a curved path of the hand through the external world. Again translated to our application, it would then be more intuitive to have a vibrotactile actuator stimulate the muscle that needs to be contracted to establish the wrist rotation. As indicated in the next section, we investigated two alternatives (below referred to as ‘pull’ and ‘push’) for each candidate principle.

1.2 Task description

As stated earlier, we used a simple wrist rotation task to investigate intuitive vibrotactile coding of movement initiation. We will first describe this task and then formulate the research questions. Figure 1 depicts the five locations (A, B, C, D, E) for vibrotactile actuators that we tested for initiating left and right wrist rotations. To illustrate the rationale behind the selection of these five location, let us assume that we want to communicate that a person should make a wrist rotation to the left. Then what actuator location is most intuitive?

Location A may be a very good candidate because it specifies the direction in which the hand needs to be rotated. The actuator actually ‘pulls’ the hand in the required direction in the external world. This corresponds with the ‘follow-the-needle’ principle that has proven to be successful in navigation. Location B may be equally intuitive because it ‘pushes’ the hand in the required direction in the external world. Actuators at A and B are compatible with an external frame of reference for specifying direction of movement. Even though both seem to be good candidates, they may be more suitable for coding a translation of the hand than a rotation of the wrist. A vibrotactile actuator at location C stimulates the muscle to be contracted for establishing a wrist rotation to the left, and as such specifies in an intrinsic frame of reference the required movement. One could consider this as a ‘pull’ in an intrinsic frame of reference. An actuator at location D also stimulates a muscle, but then the one that should be contracted to establish a wrist rotation in the opposite direction: a