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The effect of actual and imaginary handgrip on postural stability during different balance conditions

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ABSTRACT

The stabilizing effect of holding an object on upright posture has been demonstrated in a variety of settings. The mechanism of this effect is unknown but could be attributed to either additional sensorimotor activity triggered by a hand contact or cognitive efforts related to performance of a supra-postural task. A potential mechanism was investigated by comparing postural stability in young healthy individuals while gripping a custom instrumented wooden stick with a 5N force and while imagining holding the same stick in the hand. Twenty subjects were tested during three standing balance conditions: on a stationary surface, on a freely moving rockerboard, and with an unexpected perturbation of 10° forward rockerboard tipping. Postural stability was evaluated as velocity of the center of mass (COM) and center of pressure (COP) compared across all experimental conditions. COM and COP velocities were equally reduced when subjects gripped the stick and imagined gripping while standing stationary and on the rockerboard. When perturbed, subjects failed to show any postural stability improvements regardless of handgrip task. Results indicate a stabilizing effect of focusing attention on motor task performance. This cognitive strategy does not appear to contribute any additional stabilization when subjects are perturbed. This study adds to the current understanding of postural stabilization strategies.

1. Introduction

Maintenance of upright posture is a complex action requiring the integration of information from multiple sensorimotor and cognitive systems into a postural control scheme. Considering the complexity of this action, postural control is also highly influenced by performance of parallel motor (supra-postural) tasks. Recent studies conducted with neurologically intact, healthy individuals confirmed a beneficial effect of holding an external object on the stability of upright posture. Regardless of the level of contact forces applied, holding a stick parallel to the ground reduced postural sway when standing with eyes closed [1] or when perturbed by viewing a moving visual scene [2]. Similarly, postural stability was increased by gripping a load cell between the index finger and thumb when standing on a rockerboard [3] and during single leg stance [4]. While well documented, the cause and effect of increased stability from gripping an external unfixed object is not well understood.

The stabilizing effect of holding an external object can be attributed to additional hand contact with a rigid surface. Even light touching of a rigid support stimulates somatosensory receptors of the hand at the point of contact and generates signals concerning the direction, amplitude, and velocity of postural displacements [5–9]. When integrated into a common postural control scheme, this information helps activate appropriate muscles and reduce postural instability [8]. Another stabilizing factor could be the increased body stiffness due to the upper trunk and extremity muscles contraction producing light touch or holding an object [1]. Although important, all these sensorimotor outputs may not be the only factors influencing stability during performance of a supra-postural task.

Postural stability can also be induced by a cognitive effort of focusing attention on holding an object, as a secondary task. Studies have shown that subjects improve their stability when performing cognitive spatial and non-spatial memory tests [10], mentally counting backward [11], or memorizing digit combinations [12]. Postural stability was also increased by focusing

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attention on the external motor task of holding a pole horizontally while balancing on an inflated rubber disk [13]. A motor task of holding an external object in the hand puts less demand on the concentration, memory, and attention, than for example memorizing digits. However, this cognitive effort could contribute to postural stabilization during the supra-postural task performance. It should be noted that the opposite effect of decreasing standing postural stability with introduction of secondary cognitive task has also been described in the literature [14,15].

The present study was designed to investigate the effects of sensorimotor and cognitive task demands on postural stability during standing and performing a supra-postural task of maintaining a pre-determined force grip level throughout the trial. Postural stability was compared between the tasks of physically grasping an object versus only imagining grasping an object. The hypothesis was that postural stability will increase with the supra-postural tasks of maintaining a constant grip force throughout all balance conditions both with the actual and imaginary handgrip tasks in young healthy individuals.

2. Methods

2.1. Subjects

A convenience sample of twenty university students (10 women and 10 men mean age (SD) 22 ± 1.8 years) with no known musculoskeletal or neurological impairments participated in the study. All subjects signed an informed consent form approved by the Institutional Review Board.

2.2. Experimental set-up

Subjects were tested while standing barefoot with feet shoulder width apart on a 46 cm by 46 cm rockerboard affixed with a force plate (Fig. 1). As described previously [1] subjects held a 500 g stick (20 cm × 4 cm × 4 cm) containing a force transducer. The amount of handgrip force was displayed to the subject in real-time via computer display in LabVIEW (National Instruments, Austin, TX). This design follows previously used paradigms that incorporated hand grip or loosely hanging objects with the addition of supra-postural task regarding the manipulation of the object [1,16].

Subjects were instructed to stand in a relaxed upright stance for a 15-second trial with arms at their sides. Three balance conditions and three tasks were tested in sequence. The three balance conditions included standing on a fixed rockerboard (hereafter defined as stationary, Fig. 1), on a freely moving rockerboard (rockerboard), and on a freely moving rockerboard while being unexpectedly perturbed (perturbation). The perturbation was applied by a quick tilting the rockerboard forward 10° in a toes down direction. Instruction provided to subjects consisted of encouragement to "stand normally and look straight ahead" at the beginning of each trial. Before the first perturbation trial subjects were encouraged, as before, to stand normally but no further explanation of the perturbation was given. All subjects were able to maintain upright stance while keeping the feet in place on the rockerboard and without stepping off during the perturbation condition recordings.

At each of the three balance conditions, subjects performed three tasks: holding nothing (no grip), gripping the stick at predetermined force level 5 N (handgrip), and imagining gripping the stick at 5 N (imaginary grip). During handgrip task trials, the stick was held parallel to the ground in the dominant hand with the middle finger aligned across the center of the load cell. Subjects were trained to establish the correct force level by looking at the LabVIEW monitor and then to look forward at the wall while maintaining the grip level at which time data collection began. Each balance/grip combination was repeated three times resulting in 27 trials per subject. Brief periods of rest were given during set-up and in-between trials.

2.3. Data collection and analysis

Reflective 20 mm diameter markers were attached to major bony landmarks and to the 4 corners of the rockerboard to track movement and to define the initiation and completion of the perturbation throughout the 15-second trials sampled at 50 Hz. Movement of the markers were recorded using a motion capture system (Qualisys QTM, Gotenburg, Sweden) and the analog signals from the load cell and force plate were synchronized with the marker data for analog-digital conversion (USB-2533, Measurement Computing Corporation, Norton, MA). From the filtered data subject COM was calculated using anthropomorphic tables. Average, that is root-mean-square (RMS) and maximal velocity of the COM path, including displacements in X, Y, Z directions was analyzed in a custom MATLAB script that accounted for initiation and completion of the perturbation. Center of pressure (COP) on the force plate was calculated and transformed to a global system to account for the angular perturbation of the rockerboard. Sagittal plane COP was analyzed by identifying instantaneous equilibrium points and then decomposing COP into rambling and trembling components [17]. COP and also rambling and trembling were temporally differentiated to determine velocities. Repeated measures two-way ANOVAs with Tukey's HSD post hoc tests were used to analyze the effects of experimental condition (stationary, rockerboard, perturbation) and handgrip task (no grip, handgrip, imaginary grip) on average and peak COM velocity and average and peak COP, as well as rambling and trembling velocities, respectively.

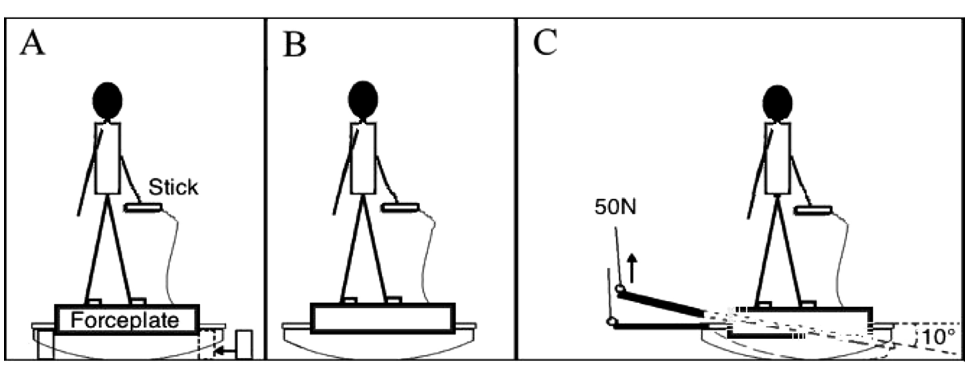

Fig. 1. Experimental conditions and apparatus. (A) Subject standing on stationary rockerboard surface holding stick calibrated to measure handgrip force. (B) Subject standing during freely moving rockerboard condition. (C) For the perturbation condition ~50 N force was used to tip the rockerboard forward from the back of the board. This displaced the subject in a toes down direction by 10° at which point the subject is required to stabilize to maintain upright position.

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3. Results

3.1. General description

Subjects demonstrated a large amplitude sagittal sway when standing and performing no grip task (Fig. 2). However when required to focus on an actual or imagined handgrip force the subjects reduced sway amplitude and adopted a more frontal sway pattern. During the rockerboard condition the COP trajectory was reduced only when gripping the actual stick (Fig. 2B). A similar tendency of decreasing COP displacements during both actual 5 N and imaginary tasks in stationary and rockerboard stance was observed in most subjects. This tendency was not seen during the perturbation condition.

3.2. Average COM velocity

Confirming individual means, the average COM velocity was highly influenced by the balance conditions ($F_{2,57} = 11.73$, $p < 0.001$). Average COM velocity was increased when perturbation was applied compared to stationary ($p < 0.001$) or rockerboard conditions ($p < 0.001$, Fig. 3). However, no significant difference in average COM velocity was found between the stationary and rockerboard conditions ($p > 0.05$, Fig. 3A). In general the grip task did not change postural stability across all three balance conditions ($F_{2,171} = 0.47$, $p > 0.05$). However compared to the no grip task, the handgrip and imaginary grip reduced average COM by at least 33% ($p < 0.05$) during the stationary condition and by at least 24% ($p < 0.05$) during the rockerboard condition. No significant reductions in velocity were found between any task types when the perturbation was applied ($p > 0.05$).

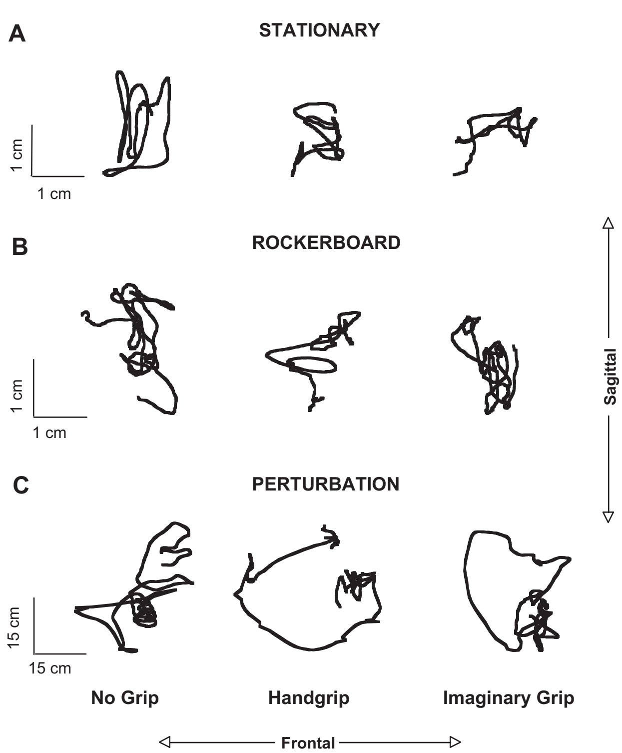

Fig. 2. Trajectories of the COP path of a representative subject during standing in (A) stationary condition, (B) rockerboard condition and (C) perturbation condition; each with separate trajectories for each task. Trajectories of COP aligned in the sagittal and frontal planes.

3.3. Maximal COM velocity

The peak COM velocity also was influenced by balance condition ($F_{2,57} = 376.46$, $p < 0.001$, Fig. 3B). Regarding comparison of task means, peak COM velocity during the stationary condition was reduced with both handgrip and imaginary grip tasks ($p < 0.001$). However, during the rockerboard condition only the imaginary grip appeared to increase subject postural stability ($p < 0.05$) while the task of grasping the stick at 5 N had no effect ($p > 0.05$) compared to no grip. Similar to the average COM velocity findings, no stabilizing effects on peak COM velocity were found during the perturbation condition regardless of handgrip task ($p > 0.05$).

3.4. COP velocity

Three parameters were used to analyze the COP velocity including maximal, rambling, and trembling velocities. ANOVA showed significant effect of standing condition on all three velocities ($F_{2,57} = 80.22$, $p < 0.001$ for maximal; $F_{2,57} = 59.28$, $p < 0.001$ for rambling; and $F_{2,57} = 285.79$, $p < 0.001$ for trembling; Fig. 4). Similarly to the COM velocities, no overall grip task effect was found for the COP maximal, rambling, and trembling velocities across conditions ($F_{2,171} = 2.47$, $p > 0.5$). The handgrip reduced maximal, rambling and trembling velocity during stationary condition ($p < 0.01$), maximal velocity during standing on the rockerboard ($p < 0.05$), and the rambling velocity during perturbation condition ($p < 0.05$) from 34 to 38%, compared to the no grip task. Imaginary grip resulted in the COP velocity reduction in both stationary and rockerboard conditions ($p < 0.05$), by at least 22%. No differences in the COP rambling and trembling velocities were found between the handgrip and imaginary grip tasks.

3.5. Grip force

On average, subjects were able to maintain a continuous grip force of 5 N during stationary (mean force 4.87 ± 0.43 N) and rockerboard conditions (mean force 4.90 ± 0.43 N). During these conditions there was no significant difference in the peak force at any time ($p > 0.05$). However, during the perturbation balance condition, subjects could not maintain the 5 N force requested. At the moment of perturbation maximal grip force (mean 7.62 ± 2.37 N $p < 0.001$) increased significantly compared to stationary and rockerboard conditions.

4. Discussion

Gripping and imaginary gripping of a stick reduced average COM velocity by at least 24% for subjects standing both stationary and on a rockerboard. Smaller COM velocity is indicative of stable postural sway patterns in healthy individuals [18]. This finding is consistent with the previous study [1] and with findings of others utilizing a kinesthetic imaginary task of thumb-to-finger opposition as a supra-postural task to decrease postural sway [19]. The current experiment, to the best of our knowledge, is the first to report an equal stabilizing effect from a supra-postural motor task and the kinesthetic imagery of motor task on postural control during unperturbed standing in healthy individuals.

Many studies have found a variety of supra-postural tasks that appear to influence postural stabilization. Some of these studies have highlighted the impact of additional somatosensory feedback from contact with external surfaces or a part of the subject's body [2–4,8,20,21]. Particularly, additional somatosensory feedback or haptic supplementation has been shown to provide information about the direction and velocity of postural displacement thereby enhancing postural control [22]. In contrast, subjects deprived

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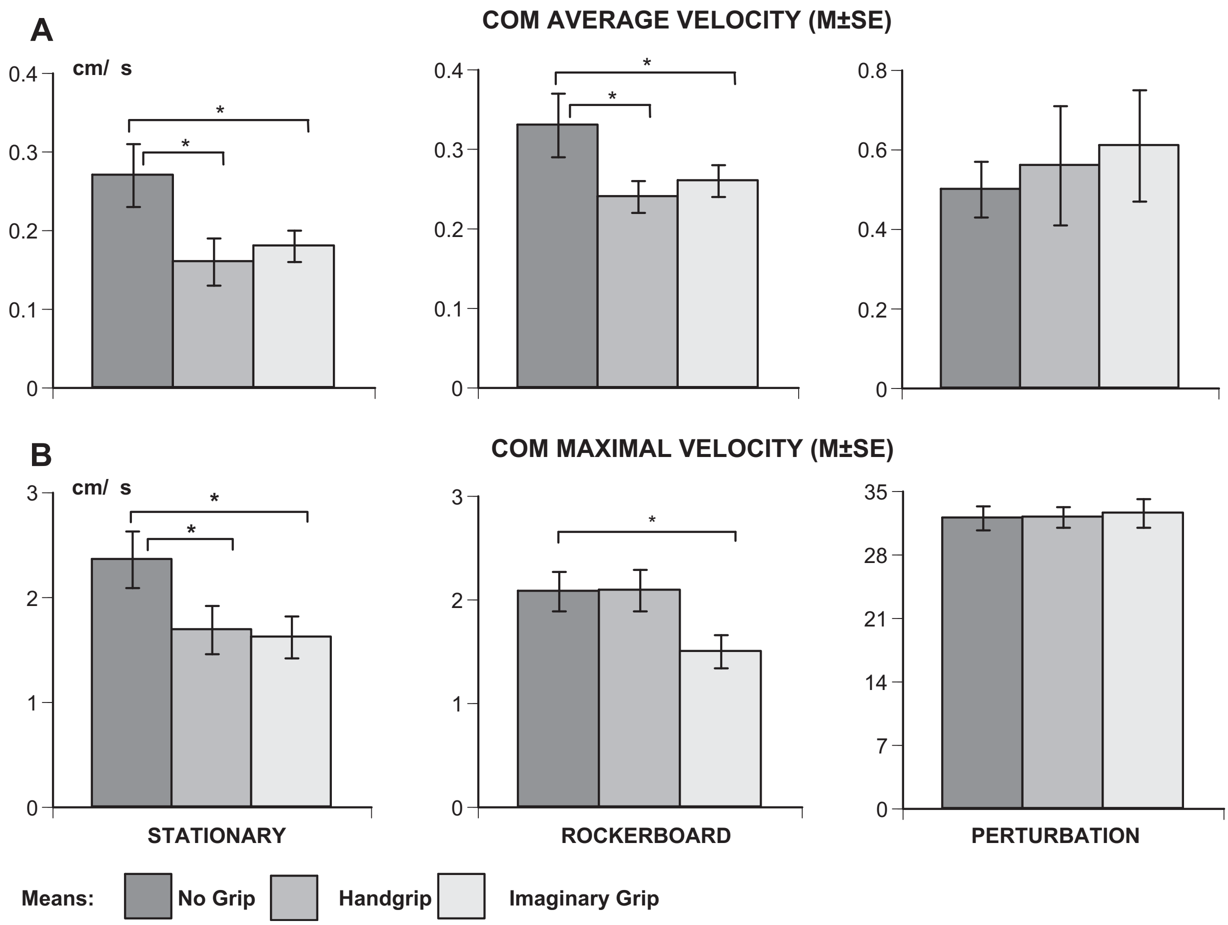

Fig. 3. Means and standard errors (M ± SE) of the average (A) and maximal (B) COM velocities for stationary, rockerboard, and perturbation conditions. The black bars represent no grip task, gray bars represent 5 N actual handgrip task, and light bars represents the imaginary handgrip task. Significant differences from control represented with an asterisk.

somatosensation by disease related or experimentally induced tourniquet ischemia were less able to utilize advantages of a supra-postural task, for example light touch, in postural stabilization [23]. Our finding emphasizes the importance of the mechanisms other than additional somatosensation for postural stabilization by performing a supra-postural task. By using kinesthetic imagery of gripping a stick our participants gained a similar amount of postural stabilization as achieved during the actual handgrip task. This effect could be explained in several ways. First, postural adjustments accompanying a supra-postural motor task are not triggered by a somatosensory feedback from hand receptors, but rather are already built into a common scheme of the whole body movement. This common scheme is available in feed-forward mode before the actual movement begins and includes postural adjustments specific to the type of movement being executed [19]. In this case postural regulation can still occur through other neural sources, for example autonomic responses from the sympathetic nervous system (see for review [24]). Another possibility is that imagining a stick grip might involve a copying mechanism that replicates the sensory feedback from a previously executed action of holding the stick in the hand [25]. Thus, the motor and sensory signals, even when not actually sent via the ascending and descending pathways, can be integrated into appropriate postural adjustments which accompany movement execution and prevent postural destabilization.

When participants were perturbed, none of the handgrip tasks produced stabilization (Figs. 3 and 4), thus partially disproving the hypothesis that stabilization would occur for all balance conditions. These results are consistent with one [26] but not all previous studies [27,28]. Previously, light touch on a fixed support as a supra-postural task when combined with a sudden perturbation resulted in no reliable postural stabilization for both healthy control individuals and subjects with diabetic neuropathy [26]. Conversely, light touch of a flat wooden end plate at shoulder level while standing resulted in faster stabilization following application of a perturbing forward body pull [27], and holding a walker improved compensatory postural adjustments when reacting to a sudden, unexpected perturbation while blindfolded [28].

These studies along with the results presented here illustrate a flexibility of postural and supra-postural task interaction, that is entirely task-dependent and that may vary in different conditions. When importance of either postural or supra-postural tasks is not specified and released from attention focus, the CNS is flexible in directing resources and selecting the most efficient way to control both tasks [29,30]. This flexible control appears to be dependent on the relative difficulty of each task and when posture is threatened remaining upright takes priority. Results from the perturbation condition support the *postural first principle* that indicates if the posture task demand is comparable to the supra-postural task demand the maintaining balance takes precedence [31]. However the experimental design and methodology may not have challenged subjects sufficiently to uncover the extent of this relationship. A body of studies using sea travel as the laboratory setting have found that even continuous real world challenges to postural stability have been matched easily by sailors modifying

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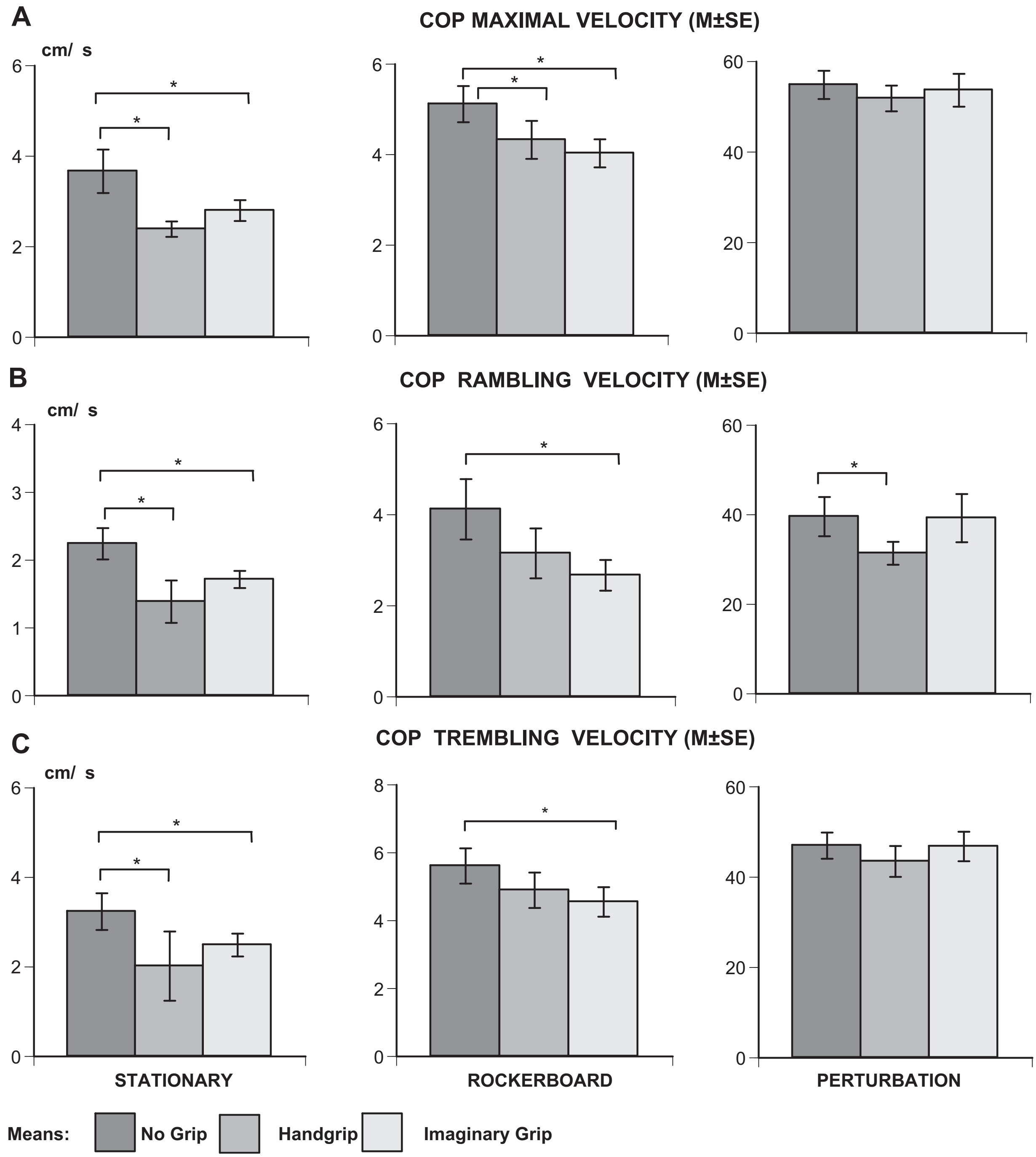

Fig. 4. Means and standard errors (M ± SE) of the maximal (A), rambling (B), and trembling (C) COP velocities for stationary, rockerboard, and perturbation conditions. The black bars represent no grip task, gray bars represent 5 N actual handgrip task, and light bars represents the imaginary handgrip task. Significant differences from control represented with an asterisk.

their postural sway well and successfully maintained their stance [32–34].

When perturbed subjects showed decreased grip force accuracy and every subject gripped the stick with more force than requested, i.e., force increased from 5.3 N to 18.5 N. This overcompensation effect was also found in the previous study [1] when subjects stood blindfolded on a rockerboard. It was postulated that subjects increased their grip force to increase somatosensory feedback to compensate for postural uncertainty due loss in visual input. Subjects in this study may have reacted similarly due to the uncertainty of the exact moment of perturbation. However this speculation is confounded by findings from a study done by Huang et al. that found that the intensity of grip force had no effect on change in COP displacement [4].

In summary, this study has shown that postural stabilization occurs during both actual and imaginary handgrip tasks when subjects stood stationary and on a rockerboard. This stabilization was reduced when subjects were abruptly perturbed, thus demonstrating a change in postural strategy regardless of simultaneous task, actual or imaginary. These results demonstrate the wide degree of flexibility the CNS has with managing somatosensory input, task demand, and environmental factors in maintaining postural stability. These findings also emphasize the need for further study into the types of motor control strategies used to maintain postural control.

Conflict of interest statement

None declared.

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