Cognitive Load Results in Motor Overflow in Essential Tremor

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RUNNING HEAD: Essential Tremor and Cognitive Load

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Abstract

SK is an 84 year-old woman diagnosed with essential tremor (ET) but no cognitive deficits. In this experiment, we tested the effects of mental rotation (a form of additional cognitive load) during reaching behavior (with the right hand) on the tremor profile of the non-moving left hand. We observed a marked increase in tremor and its variability, as well as the "freezing" of the movement pattern as effects of the cognitive load. These findings imply cognitive-motor overlaps in patients with ET, raising the possibility that the deficits reflect the loss of a common pool of neural resources, despite the heterogeneity of the symptoms of the disorder.

Keywords

Essential tremor, cognitive load, freezing, reaching, motor overflow

Introduction

Essential Tremor (ET) is a highly prevalent disorder among people over the age of 40 years, reportedly affecting 4.0% of individuals in this age group (Dogu, Sevim, Camdeviren, Sasmaz, Bugdayci, & Aral et al., 2003; Louis, Ottman, & Hauser, 1998) and 4.6% of people over the age of 65 years (Louis & Ferreira, 2010). It presents itself clinically, as tremor of the arms that persists during voluntary movement. Tremor, however, is not the only core symptom of this condition. More recent findings have highlighted the heterogeneity of this disorder, as some individuals with ET develop head tremor and/or dementia and/or Parkinson's, while others do not (see Louis, 2009 for an in-depth review).

Because the clinical features of ET do not manifest uniformly in all patients, they have often been studied using a domain-specific approach (e.g., cognitive, motor, and psychiatric). Yet, much less emphasis has been placed on the overlap across multiple functional domains. Interestingly, while many studies have found cognitive impairments in patients with ET (e.g., Benito-Leon, Louis, & Bermejo-Pareja, 2006; Duane & Vermillion, 2002; Lacritz, Dewey, Giller, & Collum, 2002; Louis, 2010; Tröster, Woods, Fields, Lyons, Pahwa, & Higginson et al., 2002), tremor severity has been found to be uncorrelated with the degree of cognitive deficit (Lombardi, Woolston, Roberts, & Gross, 2001). Previous studies have examined the motor and cognitive aspects of the problem in isolation. This leaves room to exploit the cognitive components of a simple motor task and examine if the increase in the task's cognitive demands would affect tremor levels ET. In particular, this study tests the possibility that a cognitive load could have an effect on motor patterns and tremor in a patient with no demonstrable neuropsychological deficits.

In the motor domain, spillover effects due to increased effort have been widely documented and termed "overflow." There are situations where the contralateral limb, even when uninvolved in the action, increases its muscle activity and sometimes generates involuntary movements. Such involuntary actions are observed when the moving or active limb is required to generate a high muscle force output or has become fatigued (Addamo, Farrow, Hoy, Bradshaw, & Georgiou-Karistianis, 2009; Bodwell, Mahurin, Waddle, & Price, 2003; Hortobagyi, 2005). A recent study of the overflow phenomenon provides a connection between tremor and involuntary movements (Morrison et al., 2011). When the active limb begins to approach the upper limits of voluntary movement of approximately 5 to 7 Hz (see Aoki & Kinoshita, 2001), the non-active, uninvolved limb, likewise, begins to oscillate with similar dynamics to the active, moving limb. In healthy young adult controls, however, motor overflow is generally detected only when the motor system is near the limits of its capacity (Hortobagyi, 2005).

One of the common findings in the ET literature is neurodegeneration in the cerebellum found post-mortem in 75% of the brains of patients (Louis, 2009). Although the primary role for the cerebellum has been linked to sensorimotor integration, the cerebellum has also been found to be involved in cognition and affect (Katz & Steinmetz, 2002). This finding provides possible neural underpinnings for the findings of psychiatric and cognitive declines in patients with ET, based on the hypothesis that cognitive and motor function draw on neural resources from a common pool, much like a brain (Satz, 1993) or cognitive (Stern, 2002) reserve. If the cognitive and motor systems draw on a pool of resources in ET that has been reduced in size due to neurodegeneration, one would expect that a cognitive load could result in motor overflow. The *first question* that the current experiment addresses is whether motor overflow into the non-moving arm occurs due to an added cognitive load, even in a patient with ET who exhibits no overt deficits in cognition.

A *second question* is whether the increase in tremor magnitude would be accompanied by an increase in tremor variability. The concept of a linear “signal-noise” relationship (Harris & Wolpert, 1998; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979) has long been considered in human motor control. Effectively, it is hypothesized that increasing the size of the centrally generated motor command results in an increase in the variability of the motor output. This could provide insight into whether this linear relationship remains intact in a patient with ET and if increases in tremor can be attributed to an aberrant signal-noise relationship in the neuromotor system.

The *third question* that we seek to test is whether "freezing" in the motor system occurs in ET as the result of an added cognitive load. Particularly prevalent in human gait, freezing is equated to the sensation of being stuck in place with an inability to execute a desired movement or motor plan (Giladi, 2001). Widely demonstrated in Parkinson's disease, freezing of movements is often documented in patients when the neuromotor system is taxed. Freezing is a phenomenon that particularly affects the initiation of walking (e.g., Giladi & Hausdorff, 2002; Giladi, McMahon, Przedborski, Flaster, Guillory, & Kostic, et al., 1992; O'Shea, Morris, & Iansek, 2002), but has also been observed in speech production (Ackermann, Gröne, Hoch, & Schönle, 1993). This is an opportunity to observe whether motor overflow is associated with freezing phenomena when the neuromotor system is pushed toward its limits.

The present experiment tested whether motor overflow could be induced through the addition of a cognitive load, resulting in increased tremor in the non-moving arm. Here, we add a mental rotation component to a simple reaching task, effectively requiring the participant to create a motor plan prior to the reach, while measuring the acceleration profiles at the wrist of the non-moving hand in an ET patient with no clinically diagnosed cognitive deficits.

Case Report

SK is a right-handed 84 year-old woman who has been diagnosed with having essential tremor by a movement disorders specialist. She first noticed her tremor symptoms 20 years ago with an increase in intensity for the past 4 years, which started at the hands and has recently progressed to include her lips and neck. The tremor intensifies when she has to drink or use utensils to eat. SK can however write well despite not taking any medication for her kinetic tremor.

She presents no asymmetry of the tremor which over the years has been confined to her upper body and only recently started to affect her lips and neck.

At the time of this experiment, SK has never been clinically diagnosed with cognitive deficits or psychiatric issues. However, a trained psychologist administered the Montreal Cognitive Assessment (MOCA) and she received a score of 23/30, which is below the normal range of >26/30, which places her within the range of mild cognitive impairment. Her main problem on the MOCA was on the delayed recall for un-cued words. She had problems recalling the words at the end of the session unless cued. SK continues to maintain an active social and family life that includes surfing the web and keeping up with current political issues and events. She balances her checkbook and keeps track of her finances on her own. Apart from her tremor symptoms, she could be considered to be a normally aging senior citizen. A list of the prescription medications taken by SK is presented in the Appendix. She is currently only prescribed medications primarily for cardiovascular conditions and does not take any psychiatric or neurological medications that could alter her cognitive state. She has no mobility issues, walks regularly and enjoys socializing with her family and friends.

Experimental Paradigm

Materials and Apparatus. A Polhemus (Colchester, VT) Liberty motion-capture system was used to sample position and orientation at 240 Hz. Sensors were attached to the forehead (1), trunk (1), both shoulders (2) (acromial positions), both upper arms (2) (brachial positions), both forearms (2) (ante brachial positions), and both hands (2) (on the top, manus position, opposite to the palms). A 48 cm diagonal monitor (1024 × 768 resolution) was used to display the stimuli one at a time to the participant. A wooden dowel 18 cm in length was used by the participant during their reaches to the stimuli on the screen. The dowel was no heavier than a regular wooden pencil.

Design. We asked SK to perform simple forward reaches to a stimulus target and immediately after she had completed the reach toward the screen, to return her hand to a comfortable resting position. During the forward reach, SK was asked to match the orientation of the dowel held in her hand with that of a cylinder presented on-screen. She was asked to perform the movement at one of two instructed speeds, presented in random order on-screen prior to the start of each trial (fast or slow). The forward movement had a well-defined set of goals (position, orientation, speed) whereas the supplemental retracting segment was incidental to the task. The stimulus cylinder would appear at 1 of 5 possible positions on the screen (upper left hand corner, upper right hand corner, lower left hand corner, lower right hand corner and center) and in 1 of two possible orientations (vertical or horizontal). This produced 20 trials per block.

The cognitive load was added to the task by using a primed reaching condition that required mental rotation prior to the initiation of the reach. We primed the task by displaying an upside-down (or sideways) coffee mug next to the stimulus cylinder on-screen. SK was then instructed to reach toward the screen and orient her hand "as if to grasp the coffee mug and drink from it." This condition was termed primed-DOWN. Thus, correct mental rotation required pronating her arm in vertical trials and supinating her arm in horizontal trials. The control condition (no cognitive load) allowed SK to freely select the orientation of her hand during the reach, without any cup priming. Within the priming case there were configurations of the cup that demanded the exact same kinematics as the default (control) case where no cup was presented. In such cases the cup was upside-up. These were termed primed-UP. Any differences in this condition could not be exclusively traced back to the additional motor effort from the wrist rotations of primed-DOWN as the default control condition was identical in terms of biomechanical constraints.

The experimental protocol was approved by the Rutgers University Institutional Review Board.

Procedure. SK was seated in front of the computer monitor at a comfortable distance of 50 cm, subtending an approximately 42° visual angle. Prior to the beginning of the experimental session, SK was shown examples of the control and priming stimuli and given a chance to practice reaching to both stimuli in the prescribed manner. She was told that when a stimulus appeared on the screen she was to merely observe where it appeared and to not reach to the target until the stimulus disappeared. Each stimulus was displayed for 5 seconds with a 5 second interval of a black screen between each stimulus to provide enough time for her to perform her reach. Prior to the start of each trial, SK rested her right hand comfortably in her lap. She was instructed to initiate her reach once the stimulus has disappeared. The task was to align and orient the dowel with that of the stimulus cylinder that had disappeared from screen just before movement onset. During the entire task, her non-active, left hand rested in her lap, palm down.

In this configuration, wrist motion of the left hand is confined to the fingers coming off the thigh. Lifting the wrist off the thigh is mechanically difficult as it requires movement of the heavier forearm and rotation about the elbow joint. As a result, our studies differ from conventional tremor studies that place the target effector in position where the oscillations are distributed equally above and below the neutral position. Furthermore, previous studies of tremor have explicit instructions to the subject to hold the target effector as still as possible. Here, forearm muscles for dorsiflexion pull the fingers up off thigh resulting in positive angular acceleration, with no explicit instruction to return to the resting position. Thus, larger mean angular acceleration values indicate larger amplitude upward twitches that are not accompanied by an equal and opposite downward acceleration. In addition, this leads to independence between the mean and standard deviation of the angular acceleration values.

Insert Figure 1 About Here

The experiment consisting of ten total blocks, five default and five primed, were run, with stimuli randomized within block. Originally, the data collection planned for a total of 200 trials (5 blocks × 2 speeds × 2 orientations × 5 positions × 2 conditions) collected during the course of the experiment. The entire experiment took approximately 1 hour from consent to debriefing. Data from 176 trials (85 default and 91 primed) are presented here, as SK begun to fatigue at that point and decided not to continue with further trials. Data were collected in 7 second increments, and if the movement was initiated or completed outside this window the beginning or ending of the trial was truncated, and therefore had to be dropped from the analysis. Additionally, paired sample *t*-tests require an equal number of trials in each condition, so the final 6 primed trials were dropped for these analyses.

Insert Figures 2 and 3 About Here

Data Analysis and Statistical Testing. We measured tremor in the hand wrist by obtaining the angular acceleration at the wrist joint of the left hand. Three dependent variables were obtained from the left hand tremor time-series: 1) mean angular acceleration; 2) the *within-trial SD* of the angular acceleration time-series; and 3) the decay in variance explained by the principal components.

To achieve this, position data from the Polhemus system were double differentiated to obtain acceleration values about the wrist. A similar procedure was conducted to obtain linear acceleration values of the motions of the 10 body segments along the X, Y, and Z axes of motion, which were then compressed onto a single dimension using the Euclidean norm. Effectively, this provides the resultant vector (i.e., primary direction of motion) of the body segment. Built-in software filters minimized the presence of noise so first and second rate of change of position do not amplify possible instrumentation error. We use the Motion Monitor software from the Inn Sports Inc. which has several built in filtering algorithms to handle instrumentation noise. These include Chebyshev filters, Butterworth filter and frequency domain filters (Williams, 2006). The data was filtered with a second-order low-pass Butterworth filter (cutoff frequency 20Hz).

Note that we did not include an age-matched control subject in this experiment because of the use of angular acceleration of the wrist as our measure of tremor. Control subjects simply did not exhibit a sufficient amount of wrist flexion (i.e., fingers coming off the lap), resulting in angular acceleration that showed up as a flat line.

We conducted Principal Component Analysis (PCA) on the correlation matrix of the linear accelerations of the: 1) head; 2) thorax; 3) shoulders; 4) upper arms; 5) lower arms; and 6) hands of the subject, for a total of 10 time-series. Note that we used the correlation matrix to allow for an equal comparison of the segments such as the head and torso that move with a much smaller amplitude than the right arm. Otherwise, the PCA will primarily reflect the behavior of the limb segments with the largest amplitude (Daffertshofer, Lamoth, Meijer & Beek, 2004). The PCA is a technique that is used in the study of human movement to detect the "independence" of the motions of different joints or limb segments (see Daffertshofer et al., 2004 for an in-depth tutorial). This approach has been used to detect changes in the coordination of movements as the result of motor learning (Chen, Liu, Mayer-Kress, & Newell, 2005; Hong & Newell, 2006) as well as in response to low back pain (Lamoth, Daffertshofer, Meijer, & Beek, 2006). Using the PCA, the linear acceleration data from the various limb and body segments can be broken down into principal components that account for a decreasing proportion of the total variance contained within the acceleration data. As a result, a more rapid decay in variance explained across the principal components suggests that fewer principal components are needed to describe the data set. This would suggest that there is less independence or a "freezing" of the limb segments. Tresilian, Stelmach, and Adler (1997) employed a similar PCA analysis of upper limb movements in Parkinson's patients during a reach-to-grasp task, but, without an added cognitive load (as employed in the present study). To obtain the rate of decay, we estimated the exponent of the power law function using a least squares linear fits of the log-log transform of the principal components and variance explained. The log-log transform allows a 2-parameter power law fit in the following way:

$$Y = aX^{-b} \;\; is\ equivalent\ to\ log\ Y = loga - b\ log\ X$$

where Y is the variance explained and X is the principal component. The slope of the linear function, b, is the exponent, where a steeper slope is indicative of a more rapid decay in variance explained. This is where we diverge from Tresilian et al. (1997) who were primarily interested in how many principal components were required to capture 99% of the total variance in their data.

In order to also account for the speed of movement, we also measured the peak linear velocity of the right hand during each trial. Paired t-tests were used to compare the effect of the cognitive load on the dependent variables. Effect sizes are provided as a partial η^2, where 0.1 is considered to be small effect, 0.25 is a medium effect and 0.4 is a large effect, as per Cohen (1988). Further partial correlations, controlling for condition, were conducted to detect relationships between the variables.

Results

As a result of the cognitive load the average angular acceleration of the left hand during the trial more than doubled (Control = 0.045 ± 0.042 rad/s^2 vs. Primed = 0.093 ± 0.044 rad/s^2), $t(1,84) = 9.56$, $p < .0001$, $\eta_p^2 = .521$. Variability, as measured by the SD of the angular acceleration also increased significantly from 0.044 ± 0.100 rad/s^2 to 0.070 ± 0.038 rad/s^2, $t(1,84) = 2.38$, $p = .02$, $\eta_p^2 = .063$. The PCA exponents increased significantly from 1.56 ± 0.27 in the control condition to 1.73 ± 0.26 for the primed due to the cognitive load, $t(1,84) = 4.21$, $p < .0001$, $\eta_p^2 = .174$. Representative plots of the decay in variance explained as a function of principal components is presented in Figure 2. A summary of the significant effects can be seen in Figure 3. Condition did not significantly affect the peak linear velocity of the right hand during the movement, $t(1,84) = 1.72$, $p = .090$; $\eta_p^2 = .034$. The velocity values were 0.65 ± 0.21 m/s for the control condition and 0.71± 0.26 m/s during the primed

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Insert Figures 2 and 3 About Here

We also observed significant, positive partial correlations after controlling for condition. The exponent of the PCA was significantly correlated with all of the variables (i.e., peak velocity, mean angular acceleration and SD of the angular acceleration of the left hand). The SD of the angular acceleration was significantly correlated with mean acceleration. Interestingly, peak velocity of the right hand was not correlated with the SD of the angular acceleration of the left hand, even with a zero-order correlation ($r = .043$; $p = .574$). The complete correlation matrix is presented in Table 1. A scatterplot of the strong significant correlation between mean angular acceleration and the within-trial SD of the angular acceleration is presented in Figure 4. It is important to note the three outliers in the control condition that increased the between-trial SD seen in Figure 3B. Otherwise, the control and primed conditions are clearly delineated and form two distinct data clusters.

Insert Table 1 and Figure 4 About Here

Discussion

Our results provide initial evidence of a cognitive-motor overlap in ET. We were able to alter the tremor magnitude and pattern of variability in the non-moving hand in SK by challenging her to develop a motor plan that involved mental rotation prior to a reaching movement. These findings address the *first question* and support the idea that the heterogeneity in the presentation of symptoms across domains in ET could arise from the shortage of neural resources. This is consistent with the concept of cognitive and brain reserves (Satz, 1993; Stern, 2009) and that ET is neurodegenerative (Louis, 2009). Because SK exhibits no overt cognitive impairment, it is interesting that increased tremor can be elicited in the non-moving hand by the addition of the mental rotation (i.e., increase in cognitive load) to the motor task. Moreover, SK exhibited increased tremor under cognitive load that is consistent with the idea that a shortage of cerebellar resources would result in a cognitive load impinging on resources for sensorimotor function. Once thought to be solely for sensorimotor integration, the cerebellum has now been shown to also be involved in cognition and affect (Katz & Steinmetz, 2002) a region of the brain where neurodegeneration if accelerated in ET (Louis, 2009; Tröster et al., 2002).

Although cognitive load increases the tremor in the non-moving hand, the lack of a significant difference in peak hand velocity of the moving arm shows that our results are not due to the cognitive load inducing a slowed reaching movement. In fact, reaches performed during the primed conditions were actually slightly faster (though this difference was not statistically significant) than those performed during the control condition. This provides evidence that the added mental rotation requiring a motor plan prior to the execution of the movement played a role in increasing the tremor and the magnitude of its variability in the non-moving hand. Much like motor overflow due to the execution of high force movements or fatigue seen in healthy subjects (Addamo et al., 2009; Hortobagyi, 2005), the cognitive load on SK had significant effects on the tremor of her non-performing arm akin to the overflow effect. A particularly interesting point to note is the weak correlation between the peak velocity of the moving hand and the angular acceleration in the left hand (Table 1). The lack of relationship between the movement velocity of the right hand and the tremor of the left suggests requiring SK to speed up her movements would not have induced the motor overflow.

Interestingly, a linear signal-dependent noise relationship is maintained in the current study, as evidenced by the significant correlation between the SD and the mean angular acceleration. This finding is consistent with the concept of signal-dependent noise in motor function (Harris & Wolpert, 1998; Schmidt et al., 1979). The strong linear relationship can be seen in Figure 3 (barring a few outliers observed in trials from the control condition) and suggests that this aspect of motor function is still present in SK, and addresses the *second question*: an increase in tremor magnitude is accompanied by an increase in noise. It is important to note that this effect is present when the correlation controls for the effects of the movement condition. This raises an important question for future research as to whether the signal-noise relationship is altered in patients with ET in comparison to controls using other force-variability protocols such as the one presented in Schmidt et al. (1979). Perhaps, ET results in an aberrant signal-to-noise ratio, with a change in slope and/or intercept of the linear relationship between the mean and variance of motor performance variables.

Results from the PCA address the *third question* and suggest that some degree of motor freezing occurs in SK when the cognitive load is added to the motor task. The data point to a reduction in the independence of the movements of the body parts tracked during the task, as the exponent of the decay in variance explained was much larger during the primed movement condition. Effectively, the movements become more constrained, as the accelerations of all of the body segments were less free to vary independently. This finding is consistent with the effects of cognitive load (Giladi & Hausdorff, 2006; Giladi et al., 1992) and dual-task conditions (O'Shea et al., 2002) on motor freezing in Parkinson's. However, to our knowledge, this is the first demonstration of the freezing in the motor system in a patient with ET as the result of cognitive load. Our results suggest that motor freezing is a problem with ET patients, although, not to the same extent as in Parkinson's.

The correlation between the exponent of the PCA and the magnitude of the tremor of the left hand suggests that motor overflow and freezing might be related phenomena. This is consistent with the findings of Morrison et al. (2011), where the motor system seems to prefer to generate similar movement patterns across both arms when pushed to the limits of its capacity. We also found a relationship between the PCA exponent and movement velocity. A positive relationship between the two variables indicates that faster movements resulted in less independence in body segments that is akin to freezing. This is consistent with the findings of O'Shea et al. (2002) in Parkinson's, where it was shown that both cognitive and motor secondary tasks induced freezing effects in the patients.

Overall, this case study presents three key findings:

1) Cognitive load increases tremor magnitude and variability in the non-moving hand in an ET patient with no overt cognitive deficits. This effect was not related to either slowing down or speeding up of the movement due to rotation as the tremor is not correlated with the velocity of the moving hand.
2) Increasing cognitive load results in freezing of the motor system, as indexed by reduced independence in the acceleration patterns of the limb segments. Motor freezing, unlike overflow, increased with movement speed.

3) A linear signal-dependent noise relationship is maintained in ET, as evidenced by the mean-SD correlation.

At this time, however, there remains a possibility that SK became anxious while performing the novel rotation movements and this resulted in increased tremor. But, knowing that the cerebellum is also involved in affect (Katz & Steinmetz, 2002), it is also possible that our results could be traced back to a shortage of cerebellar resources. These preliminary findings of the present study underscores the need to utilize empirical approaches that tap multiple functional domains simultaneously in order to address ET and the heterogeneity of the symptom presentation in order to link cognitive declines with motor deficits.

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Table 1. Partial order correlations between the dependent variables while controlling for condition.

Variable	Peak Right Hand Linear Velocity (m/s)	Mean Left Wrist Angular Acceleration (rad/s^2)	Left Wrist Angular Acceleration SD (rad/s^2)
Peak Right Hand Linear Velocity	1.00		
Mean Left Wrist Angular Acceleration	-0.06	1.00	
Left Wrist Angular Acceleration SD	0.03	0.76†	1.00
PCA Exponent	0.26**	0.29†	0.24**

Note: * denotes correlations significant at the $p < .05$ level; **denotes correlations significant at the $p<.001$ level;† denotes correlations significant at the $p < .0001$ level.

Appendix: Prescription Medication List for SK

Reclast 5mg

Warfarin Sodium 3 mg one a day as needed.

Symbicort 160-4.5 two inhalations twice a day

Proair HFA 108 (90 base)

Lipitor 40mg one tablet by mouth a day

Ranexa 1000 mg xr12H-tab one twice a day

Avapro 300mg one a day

Metoprolo Succinate 50mg 1 tablet twice a day

Isosorbide Mononitrate 60 mg 1 tablet twice a day

Lasix 20 mg one, two, or three a day

Micro-K 10 mEq once a day

Levothyroxine 100mg once a day

Figure Captions

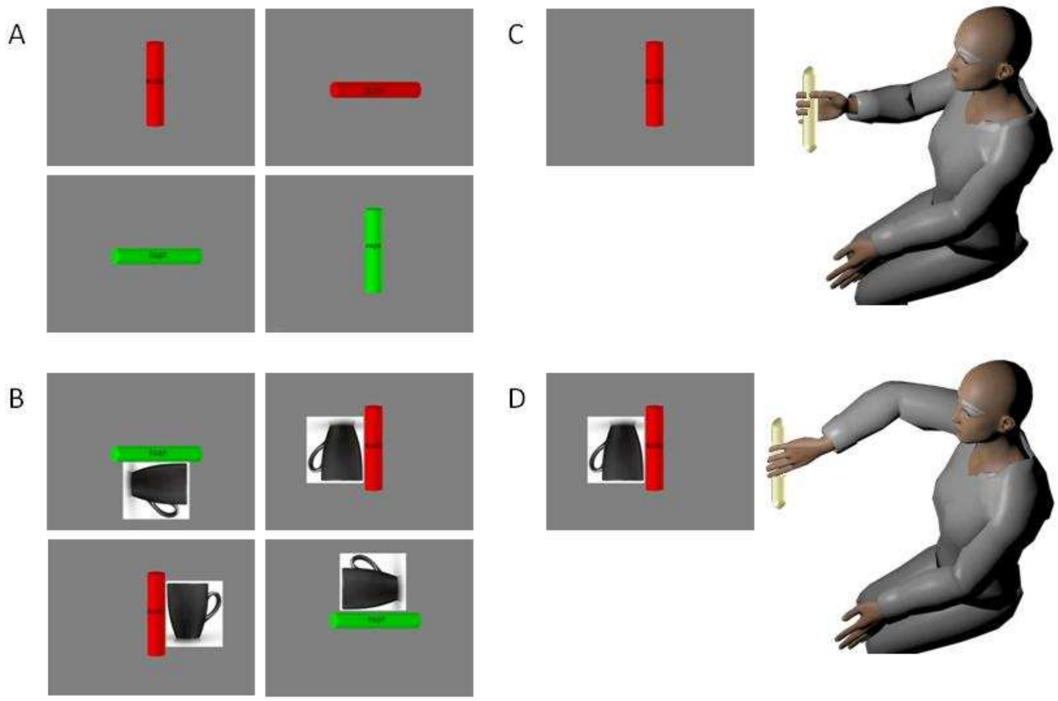

Figure 1. Illustration of the reaching task performed by SK. (A) Cylinder configurations indicating the orientation, position and speed during the default (control case). The speed was primed with a label in the cylinder (a text indicating the speed level) and with the color red for slow and green for fast. (B) Primed condition including a picture of the cup next to the cylinder orientation. Trials included the more difficult primed-DOWN cases and the primed-UP case kinematically identical to the default. (C) The default final orientation as the hand held the cylinder. (D) The primed down final orientation as the hand held the cylinder. Movements were recorded as a full loop with the instructed forward motion and the spontaneous (uninstructed retractions) but decomposed into forward and backwards segments.

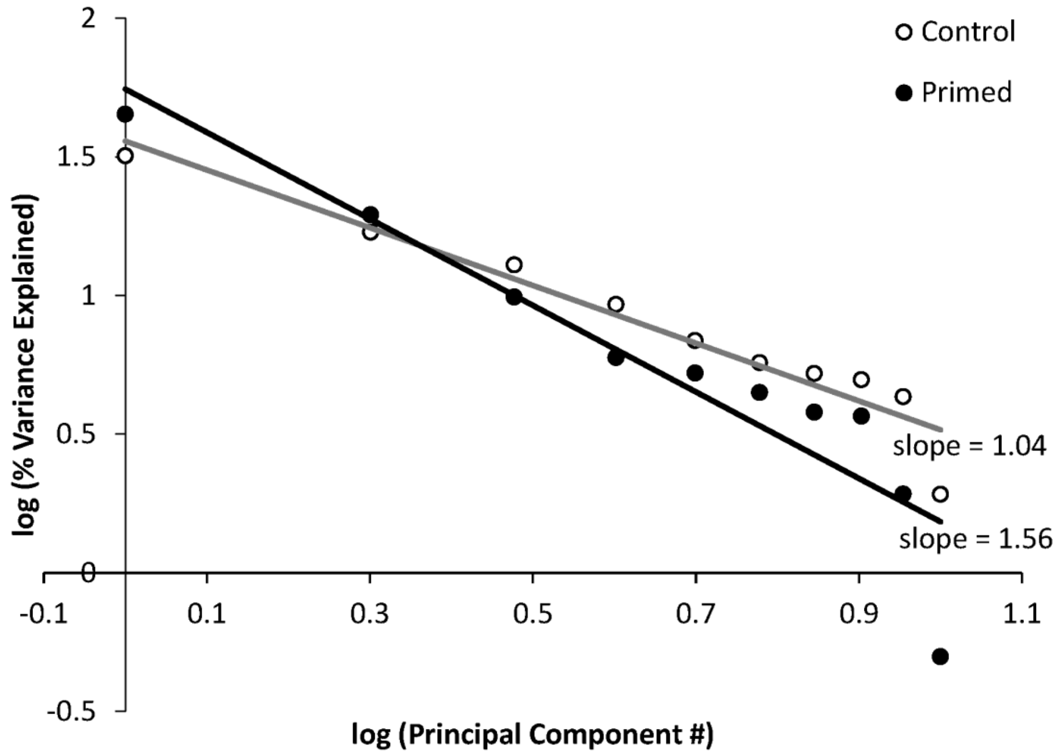

Figure 2. Representative plots of the decay in variance explained using the PCA, obtained from a single trial in each condition. The black line and circles represent data from the primed condition, while the grey line and white circles are data from a trial in the control condition.

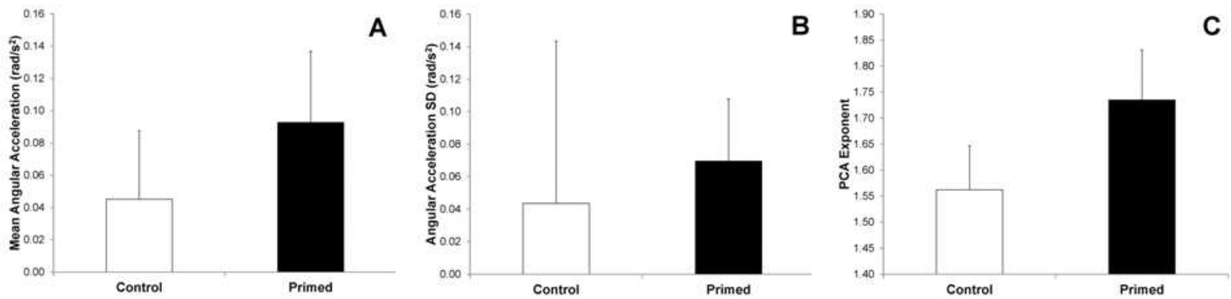

Figure 3. Bar graphs with SD error bars illustrating the significant effect of cognitive load in: A) mean wrist angular acceleration; B) angular acceleration within-trial SD; and C) PCA decay exponent.

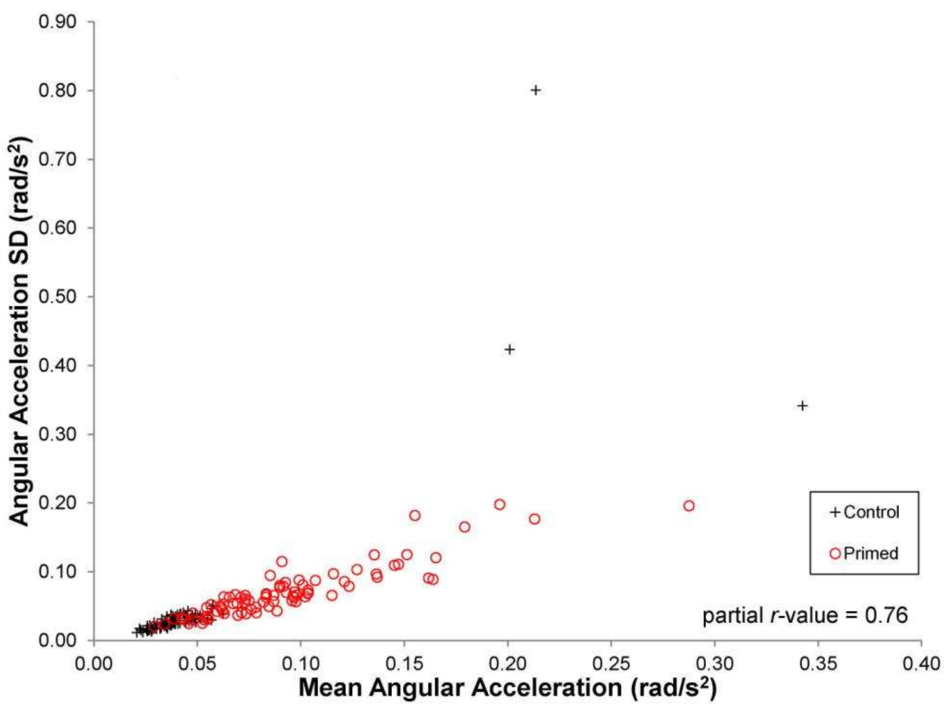

Figure 4. Scatterplot illustrating the significant correlation between mean and SD of the angular acceleration of the wrist. The different symbols reflect the primed and control conditions.

Acknowledgements

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