J Sleep Res. (2014) Regular Research Paper

Sleep continuity and total sleep time are associated with task-switching and preparation in young and older adults

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Keywords
cognition, executive function, individual differences, sleep continuity, task-switching, total sleep time

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Accepted in revised form 20 February 2014; received 14 August 2013

DOI: 10.1111/jsr.12148

SUMMARY

Ageing is associated with changes in sleep and decline executive functions, such as task-switching and task preparation. Given that sleep affects executive function, age-related changes in executive function may be attributable to changes in sleep. The present study used a sleep detection device to examine whether or not wake time after sleep onset and total sleep time moderated age differences in task-switching performance and participants' ability to reduce switch costs when given time to prepare. Participants were cognitively healthy [Mini Mental State Examination > 26] younger (n = 54; mean age = 22.9; 67.8% female) and older (n = 45; mean age 62.8; 71.1% female) adults. Using a task-switching paradigm, which manipulated preparation time, we found that smaller global switch costs were associated with lower wake time after sleep onset and longer total sleep time. Greater preparation effects on local switch costs and adoption of a task-set were associated with lower wake time after sleep onset, although this effect was significant only in older adults when stratified by age group. This association was independent of inhibition and working memory abilities. The lack of interactions between sleep and age group indicated that age differences in switch costs were not moderated by better sleep. Our results suggest that young and older adults may benefit similarly from lower wake time after sleep onset and longer total sleep time in overall performance, and individuals with less wake time after sleep onset are more likely to engage preparatory strategies to reduce switch costs and boost task-switching performance.

INTRODUCTION

Advancing age is often characterized by decline in executive function (Buckner, 2004; Kramer *et al.*, 1999). Impairments in executive function may include difficulties in selecting relevant and inhibiting irrelevant information and actions, and in monitoring and updating information (Mayr, 2001). Task-switching, a model paradigm of executive function, is often sensitive to advancing age (Monsell, 2003; Verhaeghen, 2011) beyond general age-related slowing (Wasylyshyn *et al.*, 2011). During task-switching, young adults often exert executive control to adopt a task-set that is maintained with task repetition to improve performance. However, the successful adoption of a task-set sometimes leads to a decrement in performance during task alternations (Kramer *et al.*, 1999; Kray, 2006) reflecting 'local switch costs'. While local switch costs are often similar between young and older adults, 'global switch costs' in which performance is poorer when coordinating two tasks-sets compared to maintaining a single task-set across a block of trials are often greater in older adults (Mayr, 2001; Wasylyshyn *et al.*, 2011). Thus, there appears to be age-related decline in maintenance and coordination of two task-sets (Kray and Lindenberger, 2000).

Time to prepare often leads to improved performance and a reduction in switch costs in young adults (Monsell, 2003). This is referred to as the 'preparation effect'. The preparation effect reflects the endogenous adoption of a task-set early on to benefit performance. Reduced preparation effects have been identified in older adults (Lawo *et al.*, 2012), suggesting that older adults are less likely to engage preparatory strategies to boost task-switching performance.

Despite findings that task-switching and other executive abilities decline with age, some older adults show very little impairment (Park and Reuter-Lorenz, 2009). This begs the question of which factors contribute to age-related decline in task-switching. There is evidence that factors such as sleep contribute to cognitive abilities. Prior studies have shown that older adults with greater sleep quality, quantity and continuity perform better on cognitive tasks (Tworoger *et al.*, 2006), particularly executive functions (Blackwell *et al.*, 2006; Nebes *et al.*, 2009). Given that reduced sleep negatively impacts executive functions, including task-switching (Banks and Dinges, 2007; Couyoumdjian *et al.*, 2010; Goel *et al.*, 2009), and decline in sleep continuity and quantity are prevalent with ageing (Carskadon and Dement, 2011; Ohayon *et al.*, 2004), these age-related sleep changes may play a role in age-related decline in task-switching abilities (Wilckens *et al.*, 2012).

The goal of the present cross-sectional study was to determine whether aspects of task-switching that change with ageing are associated with objective sleep measures that also change with ageing (TST and sleep continuity). We examined whether age differences in task-switching effects were lessened with better sleep. Specifically, our primary aim was to determine whether older adults with greater sleep continuity and quantity [lower wake after sleep onset (WASO) and higher total sleep time (TST)] engage preparatory strategies to boost performance during task-switching, similar to young adults. We hypothesized that older adults with lower WASO and higher TST would demonstrate preparation effects similar to young adults. In terms of global and local switch costs, we expected that WASO and TST would moderate age differences in switch costs, reflecting similar switch costs between young and older adults with lower WASO and higher TST. We expected that this effect would apply particularly to global switch costs and preparation effects, given evidence for associations between age and global switch costs and preparation effects (Lawo *et al.*, 2012; Wasylyshyn *et al.*, 2011). Where sleep was related to switch costs but did not moderate age differences in switch costs, our secondary aim was to examine whether relationships between sleep and switch costs were truly independent of age group. Consistent with the view that older adults with better sleep have better executive function abilities, we hypothesized that within the older group, individuals with lower WASO and higher TST would exhibit lower switch costs with time to prepare, and exhibit greater preparation effects.

METHOD

Participants

Participants were community-dwelling young adults (ages 21–30) and older adults (ages 55–76) recruited specifically for the research study and were not drawn from a specific clinic sample. Demographic information and participant characteristics for the two age groups are provided in Table 1. Participants took part in the experiment over two sessions spaced 1 week apart. Informed consent was gained from all participants, as approved by the University of Pittsburgh Institutional Review Board. Participants were paid at a rate of $10 per hour for participation in the experiment and $50 for wearing an armband equipped for sleep detection for 1 week. Exclusion criteria included having depression or currently taking psychiatric medication, dependence on drugs or alcohol, or a diagnosis with a neurodegenerative disease. Inclusion criteria pertinent to the present data included having at least 4 days of data from a sleep detection device, a Mini Mental State Examination (MMSE) score above 26 to rule out evidence for cognitive impairment and normal or corrected-to-normal vision. Participants included in the present study completed a task-switching paradigm over both sessions of the experiment. Analyses included a total of 54 young adults and 45 older adults. Participants were not excluded based on any self-report or objective sleep measures to capture a wide range of sleep continuity and duration in relation to cognition (Table 1).

Procedure

Participants completed the task-switching experiment over a 2-days period to reduce the length of any one session and to avoid fatigue. Therefore, half the experimental trials were collected during session 1 and the other half during session 2. Participants performed a practice block, a single task block and switching blocks at both sessions. All trial types were

Table 1 Demographic information, global and local switch costs, WASO and TST averages, standard deviations and *P*-values for age differences in younger and older participants

	Younger (n = *54)*	*Older* (n = *45)*	
% Females	*67.8*	*71.1*	
	Mean ± SD	*Mean ± SD*	P-*value*
Age	22.91 ± 2.32	62.82 ± 5.98	
Years of education	16.15 ± 1.63	15.20 ± 3.16	0.06
MMSE	29.35 ± 0.87	28.82 ± 1.02	**0.007**
Delayed recall	7.20 ± 1.64	5.84 ± 1.95	**<0.001**
Trails A	21.28 ± 7.27	30.14 ± 11.38	**<0.001**
Trails B	45.35 ± 18.44	77.78 ± 37.82	**<0.001**
Digit symbol substitution	46.39 ± 6.39	34.13 ± 7.24	**<0.001**
Global switch costs			
RT (ms)	64.28 ± 82.79	101.26 ± 118.49	**0.002**
Accuracy	0.08 ± 0.09	0.11 ± 0.14	0.063
Local switch costs			
RT (ms)	18.12 ± 44.87	31.32 ± 71.06	0.053
Accuracy	0.07 ± 0.10	0.06 ± 0.11	0.144
WASO (min)	48.45 ± 26.46	63.43 ± 42.48	**0.035**
TST (min)	383.98 ± 57.90	362.38 ± 63.11	0.079

Bold *P*-values = <0.05. WASO, wake after sleep onset; TST, total sleep time; RT, reaction time; MMSE, Mini Mental State Examination; SD, standard deviation.

included in both sessions. In the task-switching procedure the cue–target interval (preparation time) varied on a trial-by-trial basis. Participants were cued on each trial to perform one of two tasks that required judgements about a single-digit number presented on the screen. For one task they judged whether the number was greater than or less than 5 (GL task). In the other task, they judged whether the number was odd or even (OE task). A circle preceding or accompanying the target number cued participants to perform the GL task. A square preceding or accompanying the target number cued participants to perform the OE task. The preparation time was either 0 ms (simultaneous cue and target), 750 or 1500 ms. A practice block comprised of 16 trials of each task and two experimental single task blocks comprised of 32 trials for each task preceded the switching block. Participants performed the GL block followed by the OE block, followed by the switching block. The switching block was comprised of a total of 96 trials: 16 trials of each cue type (GL and OE) for each of the three preparation conditions were presented randomly in the switching block with eight of each correct response type (greater than, less than, odd, even). Given the random presentation of task cues, across participants there were 79–112 task alternations, 78–111 task repetitions and two buffer trials across the two sessions. This task-switching paradigm allowed us to assess global switch costs (task repetition trials within the switching task block relative to performance in the single task block) and local switch costs (task alternation trials relative to task repetition trials within the switching block). We examined the effect of preparation time on both global and local switch costs. Fig. 1 illustrates an example sequence of trials in the task-switching procedure.

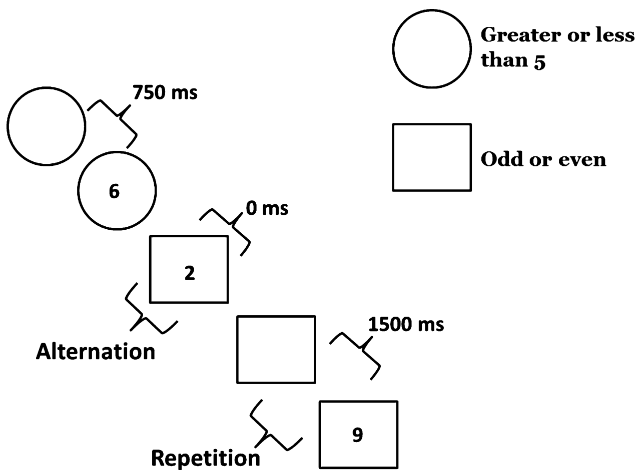

Figure 1. Example sequence of trials in the switching block: the circle cues the participant to prepare to judge whether the number is greater or less than 5. After 750 ms the number 6 appears and the participant responds ‘greater’. In the next trial, the square and number are presented simultaneously (0 ms preparation time) and the participant responds ‘even’. In the last trial, the square cues the participant to prepare to indicate whether the number is odd or even. The number appears following a 1500 ms preparation time (9) and the participant responds ‘odd’. The second trial is a task alternation (alternation from circle to square). The third trial is a task repetition trial (square to square).

Participants also completed a battery of computer-based cognitive tasks following the task-switching procedure at session 1. Included in these tasks were a version of the Stroop task with congruent and incongruent trials to assess inhibition, and an N-back task with 1-back and 2-back trials to assess working memory abilities. These tasks were used in the present study to examine whether any preparation-related improvements in task-switching were dependent upon working memory and inhibition abilities.

Neuropsychological assessments

Following participation in the task-switching procedure at session 2, participants completed a battery of neuropsychological assessments including MMSE, the digit symbol substitution subset of the Wechsler Adult Intelligence Scale III (Wechsler, 1997), Consortium to Establish a Registry for Alzheimer’s Disease (CERAD) Word List Memory test (Morris *et al.*, 1989) and Trail-making tests A and B (Reitan, 1958). Neuropsychological assessment scores are displayed in Table 1. The relationship between sleep measures and neuropsychological and computer-based cognitive tasks are reported elsewhere (Wilckens K. A., Woo S. G., Kirk A. R., Erickson K. I., Wheeler M. E. unpublished data).

Physiological data collection

A sleep detection device (SenseWear™ armband) was used to assess sleep. Participants wore the armband for 1 week between sessions 1 and 2 of the experiment. The device estimated whether participants were sleeping every 60 s based on motion, body axis, heat flux, galvanic skin response, body temperature and near body temperature (Sunseri *et al.*, 2009). TST reflected the average amount of time in minutes spent sleeping within the night-time sleep bout. WASO reflected the average number of minutes spent awake following sleep onset within the night-time sleep bout. The night-time sleep bout was guided by in- and out-of-bed times each day, as indicated in a sleep diary by the participant. WASO values were log-transformed for all analyses to correct for non-normality of the distribution.

Statistical analyses

Global and local switch costs were calculated for accuracy and reaction time (RT) on correct trials and used as the dependent variable in the present analyses. Switch costs, in contrast to absolute performance, ensured that effects of age group were not confounded by general age-related slowing in RT. To assess global switch costs, we subtracted RT and accuracy on repetition trials within the switching block for each preparation condition from performance in the easiest single task block condition (GL single task block). This reflected costs associated with ‘mixing’ tasks relative to performance when maintaining the same task (Monsell, 2003) for each preparation condition. To assess local switch costs, we compared RT and accuracy between task alternation and repetition trials within the switching block for each preparation condition. Global and local switch costs were calculated for each preparation condition to determine how switch costs were reduced as a function of preparation time.

Mixed-model analyses were used to assess whether within subject preparation effects on global and local switch costs were related to sleep measures, and whether age differences in switch costs and preparation effects were moderated by sleep. Preparation time was included in the model as a within-subjects fixed factor to account for within-subject effects of preparation when assessing main effects of sleep. It also allowed us to identify interactions between sleep and preparation to examine whether sleep had an effect on preparatory strategies. A preparation effect was operationalized as a reduction in global RT or accuracy switch costs as a function of preparation time (0 ms > 750 ms > 1500 ms). Age group and sleep (WASO or TST) were included in the models as between-subjects fixed factors. Age group was included as a categorical variable, given that we were testing two distinct age groups within the same model. Subject was included as a random factor.

We examined both main effects of sleep as well as interactions with age group and preparation. In the case of a significant sleep × age group interaction, we planned to conduct simple slope analyses to assess whether age differences varied at high and low levels of sleep (WASO and TST). We expected that age differences would be smaller in participants with better sleep. Given the distinct age groups, where significant main effects of sleep were found in switch costs across age groups, we stratified analyses by age group. This approach of stratifying by age group for main effects of sleep was used to determine whether main effects of sleep were truly exhibited independently of age group. To avoid issues with multicollinearity, separate analyses were performed for WASO and TST ($r = -0.44$, $P < 0.001$).

RESULTS

Means and standard deviations for demographic information, sleep measures and overall performance for both age groups are displayed in Table 1. Mean performance and standard deviations for the full task-switching design are displayed in Table 2. Consistent with prior reports (Wasylyshyn *et al.*, 2011), significant age differences were found in global RT switch costs across preparation times. Unlike previous findings (Wasylyshyn *et al.*, 2011), there was also a significant age difference in local switch cost RT in the 1500 ms preparation condition and a marginally significant age difference in local switch cost RT across preparation conditions. Local switch costs were otherwise not significantly different between young and older adults.

Global switch costs

WASO and global switch costs

Main effects and interactions involving WASO and global switch costs are displayed in Table 3. There was a significant association between WASO and global RT switch costs and global accuracy switch costs, such that higher WASO was associated with greater switch costs. Given that the WASO × age group interaction did not reach significance, *F*s < 1, we did not perform follow-up simple slope analyses to examine age differences as a function of WASO. However, to confirm that the main effect of WASO was truly an age-independent relationship, we stratified analyses by age group (Table 4), and found that the association between WASO and global switch costs was significant in both the younger and older groups. Thus, across age groups, there was a significant association between WASO and global RT switch

Table 2 Means ± standard deviations and age differences for global and local switch costs in RT (ms) and accuracy for each preparation condition

Preparation time (ms)	*Switch costs*	*Younger*	*Older*	*Age difference (P-value)*
0	Global (RT)	160.81 ± 60.46	212.61 ± 111.54	**0.004**
750		27.43 ± 38.05	54.81 ± 77.68	**0.025**
1500		4.60 ± 34.78	36.36 ± 71.34	**0.005**
0	Global (Acc)	0.14 ± 0.09	0.17 ± 0.14	0.251
750		0.07 ± 0.08	0.08 ± 0.13	0.536
1500		0.04 ± 0.07	0.07 ± 0.12	0.076
0	Local (RT)	38.84 ± 47.62	47.13 ± 96.15	0.579
750		18.06 ± 45.00	30.33 ± 51.36	0.208
1500		–2.53 ± 30.84	16.51 ± 54.88	**0.032**
0	Local (Acc)	0.12 ± 0.10	0.08 ± 0.11	0.086
750		0.06 ± 0.10	0.06 ± 0.10	0.973
1500		0.04 ± 0.09	0.03 ± 0.10	0.372

Bold *P*-values = <0.05. Acc, accuracy; RT, reaction time.

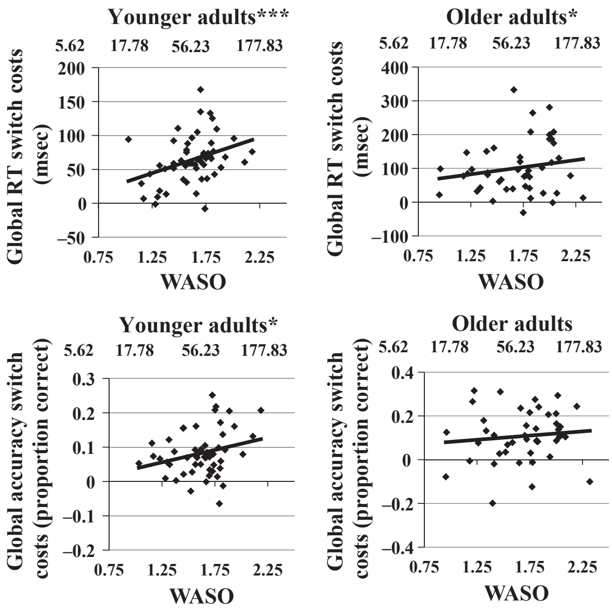

Figure 2. Shorter wake after sleep onset (WASO; better sleep) is associated with smaller global switch costs in reaction time (RT) in younger and older adults, and accuracy in young adults. Log-transformed values for WASO are displayed on the lower *x*-axis with corresponding raw WASO values on the upper *x*-axis.

costs. The relationship between WASO and global accuracy switch costs reached significance only in the younger group. There were no significant interactions between WASO and preparation effects on global switch costs. Bivariate relationships between WASO and global RT and accuracy switch costs for young and older adults are displayed in Fig. 2.

TST and global switch costs

Main effects and interactions involving TST on global switch costs are displayed in Table 3. There were significant associations between TST and global switch costs in RT and global switch costs in accuracy, such that lower TST was associated with greater switch costs. Age-stratified analyses revealed that relationships with global RT switch costs were consistent across age groups, although marginally significant in the older group (Table 4). The relationship between TST and accuracy was significant only within the younger group ($P = 0.67$ in the older group), but the TST × age group interaction was only marginally significant (Table 3). There were no significant interactions involving TST and preparation on global switch costs. Bivariate relationships between TST and global RT and accuracy switch costs for young and older adults are displayed in Fig. 3. In summary, smaller global switch costs were associated with lower WASO and higher TST across age groups. However, associations with sleep were more consistent in the younger group.

Local switch costs

WASO and local switch costs

There was a significant preparation × WASO interaction in local accuracy switch costs, reflecting that participants with lower WASO were more likely to benefit from preparation (Table 3). Local accuracy switch costs were largest, with 0 ms preparation time, and were reduced with 1500 ms preparation time. This preparation × WASO effect did not

Table 3 *F*-values for the main effects of sleep and interactions with age group and preparation for global and local switch costs across both age groups

	Global		*Local*	
	RT	*Accuracy*	*RT*	*Accuracy*
Model 1				
WASO	12.98***	4.99*	0.31	1.40
Age group	17.31***	3.29†	6.41*	1.75
Preparation	135.82***	25.32***	9.9*	12.70*
WASO × age group	0.10	0.52	0.43	0.88
WASO × preparation	0.25	0.23	0.38	4.61*
WASO × age group × preparation	0.05	0.08	0.70	1.06
Model 2				
TST	7.57**	6.83**	1.5	0.001
Age group	16.45***	2.60	7.09**	2.11
Preparation	134.41***	25.23***	9.97***	12.58***
TST × age group	0.49	3.34†	1.05	0.50
TST × preparation	0.01	0.38	0.26	0.61
TST × age group × preparation	0.59	0.18	1.52	0.32

TST, total sleep time; WASO, wake after sleep onset; RT, reaction time. †$P < 0.1$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. WASO/TST df range (1, 254.47–289.81); age group df range (1, 254.47–289.81); Preparation df range (2, 199.01–221.40); WASO/TST × age group df range (1, 254.41–288.24); WASO/TST × preparation df range (2, 201.59–219.70); WASO/TST × age group × preparation df range (2, 198.75–216.08).

Table 4 *F*-values for the main effects of sleep and interactions with preparation for global and local switch costs separately for the younger and older groups. WASO and TST were analysed in separate models. Analyses are limited to those justified by a significant main effect or interaction across age groups

	Global		*Local*	
	RT	*Accuracy*	*RT*	*Accuracy*
Younger				
WASO	15.73***	6.68*	–	–
WASO × preparation	–	–	–	0.27
TST	5.69*	19.03***	–	–
Older				
WASO	3.98*	1.11	–	–
WASO × preparation	–	–	–	4.91**
TST	3.5†	0.18	–	–

TST, total sleep time; WASO, wake after sleep onset; RT, reaction time. †*P* < 0.1; **P* < 0.05; ***P* < 0.01; ****P* < 0.001; – denotes analysis not justified by significant effect across age groups. Younger WASO/TST df range (1, 134.58–155.91); younger preparation df (2, 111.32); younger WASO × preparation df (2, 119.06); older WASO/TST df range (1, 117.55–129.90); older preparation df (2, 86.46); older WASO × preparation df (2, 88.99).

interact significantly with age group, so we did not follow-up with simple slope analyses. To further examine whether the preparation × WASO interaction was independent of age group, we stratified the mixed-model analysis by age group (Table 4). The preparation × WASO effect was only significant in the older group. The preparation effect in the younger group, $F_{(2,\ 112.67)} = 10.34$, $P < 0.001$, was not moderated by WASO. The interaction with preparation in the older group was driven by smaller switch costs associated with higher WASO in the 0 ms condition, $F_{(1,\ 43)} = 5.35$, $P = 0.026$, and smaller switch costs associated with lower WASO in the 1500 ms condition, $F_{(1,\ 43)} = 4.24$, $P = 0.046$ (Fig. 4). This interaction is consistent with the view that successful adoption of a task-set can bring about larger switch costs but, given time to prepare, switch costs can be significantly reduced. Given this rationale, lower WASO was associated with successful adoption of a task-set. There were no other significant main effects or interactions involving WASO and local switch costs for RT or accuracy (Table 3).

To further understand the relationship between switch costs and WASO, we separated accuracy by task alternation and repetition trials. Across age groups, greater repetition trial accuracy was associated with lower WASO,

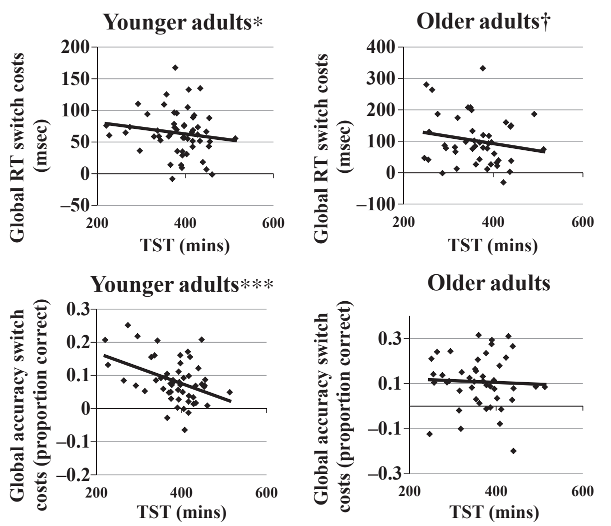

Figure 3. In younger adults, longer total sleep time (TST) is associated with smaller global switch costs in reaction time (RT) and accuracy. In older adults, longer TST is marginally associated with smaller global switch costs in RT.

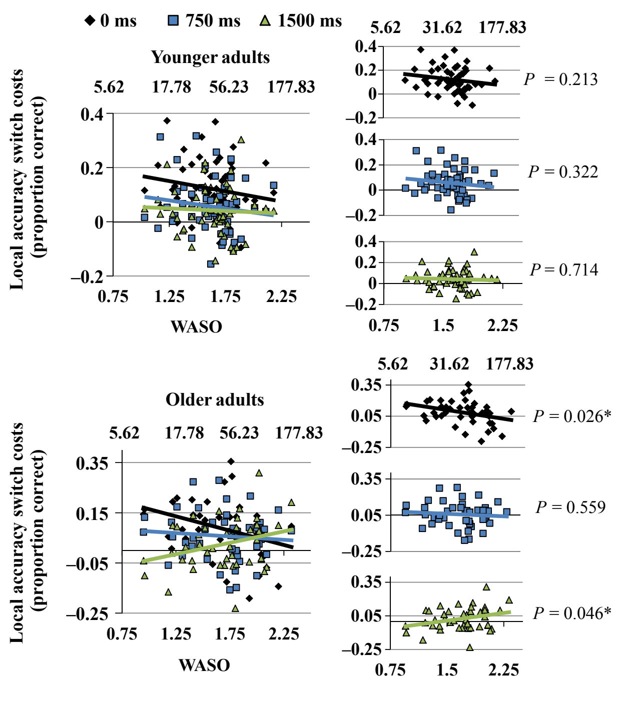

Figure 4. Left panel: in the young adult group, preparation effects on local switch costs in accuracy are consistent across levels of wake after sleep onset (WASO; log-transformed values on the lower *x*-axis and corresponding raw values on the upper *x*-axis). In the older group, preparation effects are largest at lower levels of WASO (better sleep). Right panel: bivariate relationships between WASO and local accuracy switch costs and *P*-values separated by preparation condition.

$F_{(1,283.17)} = 4.45$, $P = 0.036$. The association between alternation trial accuracy and WASO was marginally moderated by preparation time, such that participants with lower WASO exhibited a greater preparation effect, $F_{(2,\ 198.62)} = 2.256$, $P = 0.08$ (Fig. 5) . Within the older group, the WASO × preparation interaction was significant in alternation trial accuracy, $F_{(2,\ 84.12)} = 3.57$, $P = 0.032$ and was not evident in repetition trial accuracy, $F_{(2,\ 88.32)} = 0.114$, $P = 0.89$. Thus, greater preparation effects on task alternation accuracy were associated with lower WASO in the older group.

TST and local switch costs

There were no significant associations or interactions involving TST and local switch costs (Table 3). The association between TST and local switch costs was not significant for RT or accuracy. There were no interactions between TST and preparation, and no interactions between TST and age group. The TST × age group × preparation interaction was not significant for RT or accuracy. Given the lack of main effects and interactions involving TST and local switch costs, we did not follow-up with age-stratified analyses.

To summarize, greater global RT switch costs were related to higher WASO and lower TST independent of age group. In terms of local switch costs, preparation effects were moderated by WASO. Stratified by age, this interaction was only significant in the older group, indicating that given time to prepare, older adults with lower WASO were more likely to reduce local switch costs.

Inhibition and working memory abilities

We have reported above one association between sleep (WASO) and preparation. Moderation of this preparation effect by WASO may have been driven by individual differences in inhibitory control and/or working memory abilities. This possibility is consistent with the view that preparation involves inhibition of irrelevant task-sets and maintenance of task-relevant sets in working memory during the preparation interval. To test this account, we assessed whether the preparation × WASO interaction was eliminated after controlling for inhibitory control and working memory abilities. Inhibitory control was operationalized as Stroop inhibition {[(incongruent RT–congruent RT)/congruent RT] × 100}. Working memory was operationalized as 2-back accuracy, as a measure of high working memory load. We reasoned that if WASO-based differences in preparation were eliminated when controlling for inhibition and working memory, this would suggest that the preparation effect in participants with lower WASO depended upon superior inhibition of competing task-sets and maintenance of task-relevant sets. After accounting for working memory and inhibition, the preparation effect interaction with WASO remained significant, $F_{(2,\ 196.23)} = 4.658$, $P = 0.011$. This outcome suggests that the larger preparation effect in participants with lower WASO was not driven by superior inhibitory control or greater working memory abilities. Thus, there was an association between WASO and preparation that was not dependent upon inhibition and working memory abilities. Possible sources of this association are discussed below.

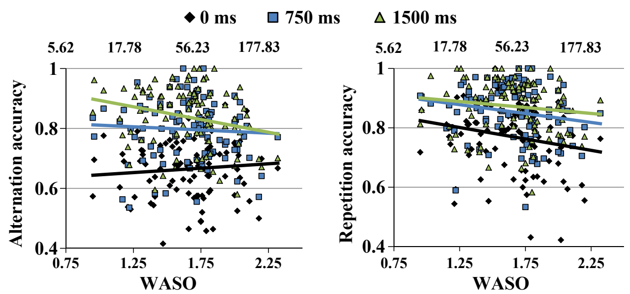

Figure 5. Alternation (left panel) and repetition (right panel) trial accuracy (proportion correct) as a function of wake after sleep onset (WASO) and preparation time across young and older participants. Preparation effects are largest at lower levels of WASO (better sleep) for alternation trial accuracy. Across preparation times, greater repetition trial accuracy was associated with lower WASO. Log-transformed WASO values are on the lower *x*-axis. Corresponding raw WASO values are on the upper *x*-axis.

DISCUSSION

Global switch costs

Across age groups, smaller global switch costs were associated with greater sleep continuity (less WASO) and longer TST. Thus, better global switching performance was associated with longer and more continuous sleep. Although associations between global switch costs and sleep more consistently reached significance in the younger group, particularly for TST, age group did not moderate the relationship between sleep and global switch costs. These findings suggest that WASO and TST are associated with the ability to maintain and coordinate switching tasks, and this relationship is independent of age.

The current findings pertaining to TST and global switch costs extend prior work examining sleep and cognition (Blackwell *et al*., 2006; Loerbroks *et al*., 2010; Nebes *et al*., 2009). Some of these studies have found little to no relationship between TST and cognition, especially executive functions (Blackwell *et al*., 2006; Nebes *et al*., 2009; Schmutte *et al*., 2007), and have proposed that sleep continuity is more important for cognition. In contrast, others have demonstrated that long and short TST are associated with poorer cognition (Loerbroks *et al*., 2010). We attribute our significant associations involving TST to the highly cognitively demanding aspects of the present paradigm and examination of switch costs in relation to TST, conceivably making this paradigm more sensitive to individual differences in TST.

It is noteworthy that associations between WASO and TST and global switch costs were demonstrated in both young and older adults. Although compared to young adults, older adults demonstrate less decrement in cognitive performance in sleep deprivation experiments (Duffy *et al*., 2009; Philip *et al*., 2004), these data suggest that both sleep continuity and duration are important in maintaining optimal cognitive abilities in older adulthood.

Local switch costs

Findings with local switch costs were more complex than those found with global switch costs. In contrast to the association between sleep and global switch costs, associations between sleep and local switch costs were specific to accuracy and were moderated by preparation. Participants with lower WASO were more likely to exhibit a preparation effect, such that switch costs were greatest with no preparation time, but were reduced given time to prepare.

Consistent with the view that better sleep (lower WASO) is associated with successful adoption of a task-set, *post-hoc* analyses separating task alternation and task repetition trials demonstrated that across preparation times, lower WASO was associated with greater repetition trial accuracy. However, for task alternations, lower accuracy with no time to prepare and higher accuracy with time to prepare were associated with lower WASO. This detriment on task alternations with no preparation time and an increase with preparation time is what occurs when a participant has successfully adopted a task-set (Monsell, 2003). When the participant is then required to switch tasks with no preparation time, task-set reconfiguration is more difficult than a participant who adopts a more diffuse task-set across all trials (Kramer *et al.*, 1999; Kray, 2006). However, with time to prepare, it is easier to disengage from a given task-set and increase performance on the task alternation trial. To that end, lower WASO was associated with adoption of a task-set and use of preparation time to reconfigure the task-set on alternation trials.

While the interaction between WASO, preparation and age group did not reach significance ($P = 0.347$), the relationship between preparation and WASO was statistically significant only in the older group. Preparation effects in accuracy switch costs were similar across values of WASO within the younger group. However, given that the interaction with age group was not significant, any differences in age-stratified analyses should be interpreted with caution. None the less, in future studies the preparation × WASO finding points to the importance of examining whether cognitive strategies differ as a function of sleep continuity and duration in older adults.

The association between WASO and preparation effects remained significant after controlling for inhibition and working memory abilities, suggesting that the association between sleep and preparation depends on a pathway other than working memory and inhibition. Beyond working memory and inhibition, greater sleep continuity may enhance attentional control, motor and attentional preparation, cognitive flexibility and possibly motivation (Erickson *et al*., 2005), leading to a greater preparation effect.

One potential mechanism underlying relationships between switch costs and WASO is that people spend less time in slow wave sleep, when WASO is higher and their sleep is more fragmented (Bonnet, 1985). Given that the greatest functional brain deactivations relative to wakefulness occur in the prefrontal cortex (PFC) during slow wave sleep, slow wave sleep is thought to benefit the PFC preferentially (Dang-Vu *et al*., 2008; Muzur *et al*., 2002; Werth *et al*., 1997). This preferential benefit to PFC function could, in turn, benefit task-switching and other executive functions (Harrison *et al*., 2000; Muzur *et al*., 2002; Wilckens *et al*., 2012).

There are some limitations to the present study, particularly in the use of accelerometer-based sleep measurement. The present study used a SenseWear (Pittsburgh, PA, USA) sleep detection device, whereas polysomnography (PSG) is considered the ‘gold standard’ for measuring sleep. While the device has more than 90% concordance with PSG in detecting sleep, Sunseri *et al.* reported approximately 50% concordance with PSG for short periods of wakefulness during sleep. Thus, WASO may have been underestimated, and in turn the overall effect of WASO on cognition may have been underestimated in the present study. If WASO was, indeed, underestimated in the present study, this would suggest that the present results are a conservative estimate of the association between sleep and cognition. None the less, the SenseWear device used here avoids some confounds associated with wrist actigraphy, such as knowing when the device is off the body by collecting additional physiological data (Sunseri *et al*., 2009). Additionally, participants need not sleep in a laboratory setting or wear electrodes, as with PSG. Future studies will benefit from examining whether PSG-measured sleep moderates age differences in cognitive performance. Electroencephalograph (EEG) oscillations recorded with PSG during sleep may also shed light on the role of neural network connectivity during sleep in relation to daytime cognitive function. Mander *et al.* (2013) found that lower slow wave sleep in older adults was associated with reduced functional connectivity within PFC–hippocampal networks, suggesting that neural synchrony during sleep strengthens connections between the PFC and functionally related brain regions. Along these lines, neuronal synchrony during sleep may also enhance connections within brain networks important for executive functions such as task-switching.

CONCLUSIONS

Sleep continuity and sleep duration of both young and older adults were associated with global switch costs. Age differences in task-switching were not diminished in participants with less WASO or longer TST. None the less, older adults' ability to engage preparatory strategies to reduce local switch costs was associated with WASO, suggesting that older adults with greater sleep continuity may be more likely to engage in preparatory strategies to benefit performance. These findings beg the question of whether improved sleep could improve cognitive strategies in older adults, and have broad public health implications, suggesting that priority should be given to establishing good sleep hygiene in both young and older adults to maintain optimal daytime cognitive function.

ACKNOWLEDGEMENTS

This project was supported by the National Institute of General Medical Sciences (T32GM081760 to KAW) and the National Institute of Mental Health (MH086492 to MEW) at the National Institutes of Health. The authors thank Afton Kirk, Krupa Patel, Marina Lukac and Leslie Denlinger for assistance with data collection and scoring.

AUTHOR CONTRIBUTIONS

KAW, KIE and MEW designed the study, KAW and SGW conducted the study, KAW and SGW analysed the data. KAW wrote the paper, with critical comments from KIE and MEW.

CONFLICT OF INTEREST

No conflicts of interest declared.

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