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Sleep quality does not influence consolidation of a visuomotor accuracy tracking task

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Alexander Wilhelm Eckerdal, Study number: 20145313
Troels Møller Pedersen, Study number: 20145274

Main supervisor: Andrew James Thomas Stevenson

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Abstract

Purpose: Sleep following motor learning training can have a positive effect on the consolidation of a new motor task. However, it has not been investigated what effect the quality of sleep can have when testing on a visuomotor accuracy tracking task (VATT). The aim of this study was to investigate whether awakenings during the night after acquisition would affect the consolidation of VATT at a 12-hour retention test.
Methods: Eighteen healthy volunteers (14 men, 4 women) participated in the study. The participants were aged 25.6 ± 1.6 years, had a height of 1.78 ± 0.10 meters and weighed 78.6 ± .8.4 kg. The participants had VATT acquisition starting between 7pm-10pm and retention tests occurred 12-hours later. The participants were divided into two groups: a disturbed sleep group and a control group. At the first session, participants performed a baseline test and six acquisition trials of VATT. At the second session, participants completed a retention test and a plateau test of VATT. The disturbed sleep group was awakened once every hour the night between the two sessions. Further measures included sleepiness using the Stanford sleepiness scale, handedness using the Edinburgh handedness inventory, and a sleep diary was filled out.
Results: The participants in the sleep disturbed group had a significant worse quality of sleep the night between acquisition than the control group ($p = 0.002$) and had a higher score on the Stanford sleepiness scale at the retention trials ($p = 0.021$). An Anova between all VATT trials and groups showed a significant main effect of time. There was an improvement of 36.4 % from baseline to the last acquisition trial across groups. There was a significant worsening with -8.1 % from the last acquisition trial to 12 hour retention across groups. The ANOVA showed no significant main effect of group ($p = 0.898$) or the interaction between group and time ($p = 0.589$).
Conclusion: These findings suggest the quality of sleep does not seem to have an effect on the consolidation of VATT. However, the disturbed sleep period was only one night and therefore does not provide information on longer periods with disturbed sleep.

Introduction

Motor learning consists of the initial phase of acquisition, where the motor skill is trained, and a consolidation phase, where memories are stabilized in long-term memory. Different factors such as exercise and sleep have been suggested to affect the consolidation of motor skills. In studies regarding sleep and motor learning different types of studies have utilized morning-evening designs, nap designs or manipulating the organization of sleep designs. Morning-evening refers to studies where participants have acquisition in the morning or the evening and have a retention test 12 hours later to compare for differences between sleeping and being awake during consolidation (Walker et al., 2002). However, this type of study design makes it hard to distinguish sleep effects from the effects of circadian rhythm. The design of a nap study is to add a nap during the consolidation phase for one group while a control group is awake (Morita et al., 2012). This type of study shows the effect of a nap and

not necessarily a full night of sleep. The type where the organization of sleep is affected are studies where the all participants still sleep but the organization is affected for example by limiting specific sleep stages (Astill et al., 2014). This type of study can give insight to what effect the quality or specific stages of sleep have.

The effect of sleep on motor learning has mostly been investigated on finger tapping tasks, which is a task investigating how many times a person can tap a sequence with their fingers inside a given amount of time. Sleep has been shown to have a positive effect on consolidation of the velocity of finger tapping tasks (Lee et al., 2012; Fisher et al., 2002; Fisher et al., 2005; Landry et al., 2015; Walker et al., 2002; Genzel et al., 2011). Sleep has also shown to have positive effects on motor learning of other skills such as playing piano (Allen, 2012), a complex sequence task on a dance mat (Genzel et al., 2012) and a walking task (Al-Sharman & Siengsukon, 2013). In the study by Walker et al., (2002), they showed that a night of sleep can result in a motor performance enhancement with up to 20% improvement in speed on a finger tapping task without loss of accuracy at a 12 hour retention test, while a wake period of the same length showed no significant improvements in both speed and accuracy.

The ability to make accurate movements is an important part of a lot of motor activities such as drinking from a cup or catching a ball. To our knowledge, there are only two published studies which have tested the influence of sleep on visuomotor-accuracy tracking tasks in humans (VATT) (Borich & Kimberley, 2011; Borich & Kimberley, 2012). In Borich and Kimberley's study from 2011, they had a morning-evening-morning group and an evening-morning-evening group with acquisition of VATT in the morning or evening. Both groups had retention tests 12 and 24 hours after the acquisition period. The morning-evening-morning group slept between acquisition and the 12-hour retention test, while the evening-morning-evening group slept between the 12-hour and 24-hour retention test. They found no effect of sleep on the consolidation of VATT. In Borich and Kimberley's study from 2012, they had one group who went through the same as the morning-evening-morning group did in their study from 2011. The participants were wearing wristbands that measured actigraphy when they were sleeping. They found a positive association between the number of hours the participants slept and the consolidation of VATT.

While the amount of sleep has a positive association with consolidation of VATT, sleep quality has been found to have a greater relation to different measures of health (depression, anger, feeling of tension, fatigue, confusion, affect balance, satisfaction with life) and sleepiness than sleep quantity (Pilcher et al., 1997). In a study, Åkerstedt et al. (1994), investigated which factors of sleep are related to the subjective feeling of sleep quality. They found sleep efficiency to be closely related to sleep quality. Sleep efficiency is the relationship between sleep and the time spent in the bed. In a study by Choi et al., (2018) thirteen children aged 6-9 practiced badminton shuttlecock bouncing performance. They found a positive correlation between sleep efficiency and improvements in shuttlecock bouncing, indicating that the children who slept the best (good sleepers had shorter sleep latency, longer total sleep time, and higher sleep efficiency than the poor sleepers), were also the ones who improved the most in shuttlecock bouncing. Another study by Appleman et. al., (2016) also investigated the influence of sleep but on the acquisition of a finger tapping task. 58 subjects wore actigraphy wristbands for four nights prior to an acquisition of a finger tapping task. They found a negative correlation between wake after sleep onset (WASO - is the time a person is awake after sleep begins) averaged across the four previous nights of sleep and the performance gains of the participants during the acquisition. WASO is a sleep measure which also is related to sleep efficiency and thereby sleep quality, which suggest that sleep quality possibly have an impact on both acquisition and consolidation of motor tasks.

The stages of sleep may also play a role in consolidation of a motor skill (Fischer et al., 2002) According to Rechtschaffen & Kales (1968), there are two basic types of sleep. These are rapid eye movement (REM) sleep and non-REM sleep (consisting of four different stages). Each of the different sleep stages are associated with different specific brain waves and neurological activity. According to Brandenberger et al. (2001), sleep cycles range between 80-120 minutes. In a study by Fisher et. al. (2002), 20 subjects performed finger tapping tasks in which they went through four conditions: two times they had acquisition of a finger tapping sequence in the evening and retention tests of the same sequence in the morning either with or without sleep in between, and two times they had acquisition in the morning and retention tests in the evening with or without sleep in between. When the participants had slept between acquisition and retention, they had a larger improvement in performance than the conditions where they were awake. There was no difference in performance improvements between sleeping during the day or during the night. They found positive correlations between the amount of time the participants spent in REM sleep compared to

improvements of performance. They saw no correlations with the time spent in the other sleep stages and the improvements in performance.

Pilot analysis

As a pilot analysis for the present study, there was a collaboration with Jesper Lundbye-Jensen from the University of Copenhagen and access was provided to data from a recent master's thesis on which he was advisor.

The master's thesis from the University of Copenhagen by Maes & Nissen (2019) investigated whether exercise before and after a VATT acquisition would give a larger increase in consolidation of the task, than only exercising before or after the VATT acquisition. Roig et al. (2012) have shown a positive effect of exercise before and after acquisition on a 24 hour and 7-day retention tests. In the master's thesis from Maes & Nissen (2019), there were 64 males who participated in the master's thesis, who were split into four-groups (exercise before, exercise after, exercise before and after and a control group). The VATT described in the method section of this study was almost the same the VATT in the master's thesis from the University of Copenhagen (Maes & Nissen, 2019). Their VATT differed by applying force to a pinching device instead of a force platform. They also had an extra baseline and retention trial with the same length as the other baseline trial, but with the sequence from the acquisition trials. Furthermore, they had two retention tests, one immediately after the acquisition and one seven days after the acquisition. The participants of the master's thesis filled out a sleep diary (the same as used in the present study - appendix 1) for the nights before and after the VATT acquisition (Maes & Nissen, 2019). They also filled out the sleep diary for the night before the 7-day retention test. These data were not used in the master's thesis (Maes & Nissen, 2019). Access was provided to the data from the sleep diaries and the results from the VATT trials. The VATT data from both baseline tests were averaged for each participant and this was also done for the retention tests. One participant was excluded from this analysis due to lack of data in their sleep diary. A two-way analysis of variance with regards to groups and their VATT trials showed a significant main effect of time ($F_{(8,472)} = 73.3$, $p < 0.001$). The participants improved VATT performance with 28.3 ± 16.6 % (mean ± standard deviation) from baseline to their last acquisition trial across groups ($p < 0.001$). There were no significant differences from the last acquisition trial to immediate retention ($p = 0.87$) or the 7-day retention ($p > 0.99$). Regardless of which exercise group the participants were in, Pearson correlations coefficients were used to investigate for

correlations between the number of hours the participants slept, VATT performance at the baseline test of acquisition, performance at the retention tests, and learning measured as the difference between the 7-day retention test and the last trial of acquisition. There were no significant correlations between hours of sleep on the day before the acquisition and performance in the baseline test, learning from the last acquisition trial (trial 6) to immediate retention or 7-day retention (all p's ≥ 0.59). There was no significant correlation between the number of hours slept on the night after acquisition and the learning from the last acquisition trial to the 7-day retention ($p = 0.77$). There was no significant correlation between the number of hours slept the night before retention and the performance on the 7-day retention test ($p = 0.47$). The participants overall perceived sleepiness was 2.4 ± 0.8 (mean ± standard deviation) on the Stanford sleepiness scale during the VATT trials and retention tests. The reason that the data did not show any correlation between their VATT performance and sleep could be because of the relatively good perception of sleepiness and small variation in the participants perception.

Summary

The two studies by Borich and Kimberley (2011; 2012) and the data from the University of Copenhagen master's (Maes & Nissen, 2019) show ambiguous results regarding the influence of sleep on consolidation of VATT. Both the study by Borich and Kimberley (2011) and the master's thesis from the University of Copenhagen showed no correlation between sleep and VATT, whereas the study by Borich and Kimberley (2012) did show an positive association between number of hours sleep and VATT consolidation. Since other studies have seen links between sleep quality and the acquisition and consolidation in other tasks (Appleman et al., 2016; Choi et al., 2018), it would be of interest to investigate whether the worsening of sleep quality has an effect on consolidation of VATT. Therefore, the aim of this study was to investigate whether awakenings during the night after acquisition would affect the consolidation of VATT at a 12-hour retention test. It was hypothesized that the awakenings during the night would affect the participants' perceived sleep quality. Because of the ambiguity with the effect of sleep on VATT there were no hypothesis dealing with the awakenings effect on VATT. If sleep have the same influence on VATT as it has on finger tapping tasks (Lee et al., 2012; Fisher et al., 2002; Fisher et al., 2005; Landry et al., 2015; Walker et al., 2002; Genzel et al., 2011), it would be hypothesized that worsened sleep quality would result in worse consolidation of VATT. If sleep does not have an influence on VATT as Borich and Kimberley (2011) and the master' thesis from the University of

Copenhagen (Maes & Nissen, 2019) suggests, then it would be hypothesized that sleep quality does not influence VATT consolidation.

Methods

Participants:

Eighteen healthy volunteers (14 men, 4 women) participated in the study. The participants had no previously known neurological, psychological or sleep disorders. The participants were aged 25.6 ± 1.6 years, had a height of 1.78 ± 0.10 meters and weighed 78.6 ± .8.4 kg. They were instructed to abstain from caffeine, alcohol, drugs and hard physical activity on the days of testing.

Study design:

The study design was a two-group intervention study (Figure 1). The participants were divided into a control group (CG) and a disturbed sleep group (DS). The groups were randomized and stratified based on the baseline result and gender using the webpage rando.la (rando.la, 2019). Both groups went through the baseline test and acquisition in the evening and then the retention test was performed 12 hours after. After the first session, both the CG group and DS group were to sleep approximately 8 hours, but the DS group was woken up by set alarms once every hour.

The first session started between 7:00 and 10:00 pm. At the start of the session participants answered the Edinburgh handedness inventory (EHI) (Oldfield, 1971) and the Stanford sleepiness scale (SSS)(Hoddes et al., 1973). These were used as a measure of handedness and alertness, respectively. Then they went through a familiarization, a baseline test and six acquisition trials of VATT. At the end of the first session, the participants were told which group they were in. The second session started 12 hours after the start time of the first session, between 7:00 and 10:00 am the following day. Between these two sessions the participants were told to sleep for 8 hours. The participants in the disturbed sleep group were told to set alarms to wake them up every hour during their sleep. At the second session, the participants answered the SSS again and completed a retention test and a plateau test of VATT.

Day 1
Preliminary examination Introduction - Questionnaires
Familiarization with VATT ~15 seconds of VATT and ~45 seconds of VATT
Baseline measurements
Acquisition trials 1-6 ~4 minutes of VATT and 2 minute break between trials
Sleep phase Both the disturbed sleep group (DS)- and the control group (CG) slept 8 hours, but the DS group was awaken once every hour

Day 2
Retention test and plateau test after 12 hours Collection of sleep diary followed by retention test and plateau test

Figure 1. Overview of the study design.

Assessment of sleep

To measure the participants sleep in the consolidation phase watches were worn during the night after the first session (Vivofit 4, Garmin, Kansas, United States of America). The watch uses data from accelerometers to measure the amount of sleep the participants slept. Furthermore, the participants were asked to keep a sleep diary, describing the time they went to sleep and the time they woke up, for the night before the first session and the night between the two sessions. A modified version of the sleep diary questionnaire used in the master's thesis from the University of Copenhagen was used (Maes & Nissen, 2019) (appendix 1). They also reported the number of times and how long the waking periods was during the night. Lastly, they also reported how deep their sleep were on a scale from 1 - 5 (1 was very light and 5 was very deep).

Visuomotor Accuracy Tracking Task (VATT)

The participants went through a familiarization of the visuomotor accuracy tracking task (VATT). The VATT used in this study was the same as the one used in the masters thesis described in the introduction. The VATT consisted of target boxes which were presented one at a time with 200 ms interval between.

During all the VATT trials participants were seated upright in a chair with their forearm of the dominant hand inserted into a device restricting movement of the arm on the table (Figure 2). They were instructed to place the index- and middle finger of the dominant hand on a force platform (Model OR6-7-1000; AMTI; Massachusetts; USA) which was connected to an amplifier (Model: MCA6 AMTI; Massachusetts; USA) adjusted to amplify the signal 1000 times. The signal was further amplified 100 times were low pass filtered (adjusted to 20Hz).

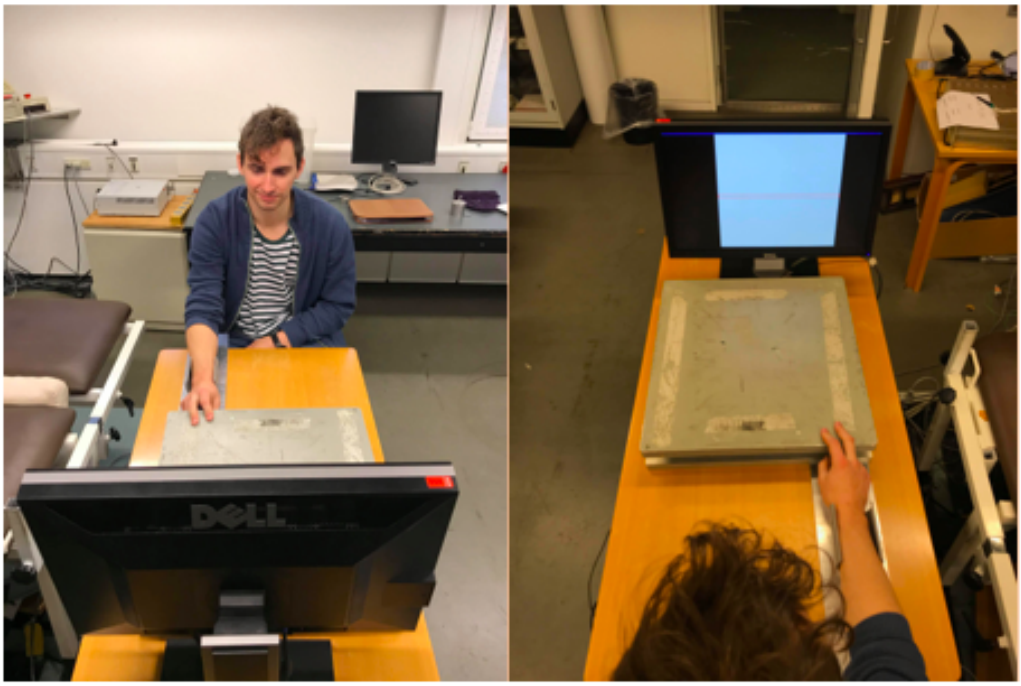

Figure 2. Experimental setup for the visuomotor accuracy tracking task.

The VATT was performed on a computer screen (1680x1050 pixels-) and consisted of a black window with a white rectangle (1000 x 1000 pixels-). In the middle of the white rectangle, the participants were able to move a red cursor vertically by flexing the index and middle finger thereby applying force to the force platform. When a greater amount of force was exerted the cursor moved up the screen and vice versa.

The participants were instructed to apply enough force to the force platform to make the cursor hit the red target boxes on the screen. The targets were presented one at a time with 2

seconds per target with a break of 200ms between the targets. The lowest target was placed at 800 pixels and the highest target was placed at 100 pixels, which is equivalent to applying forces of 7.0 N and 1.6 N. In all the trials the space between the target lines was 30 pixels, which was equivalent to 0.2 N. Before beginning the VATT the participants were informed, that their primary purpose was to get the cursor between the two target lines and hold it there as long as possible. During this the participants were provided with visual feedback by changing the color of the cursor from red (when the cursor was outside the target lines) to blue (when the cursor was between the target lines). Feedback on performance was shown on the screen after each trial in form of percentage of time the cursor was inside the target boxes.

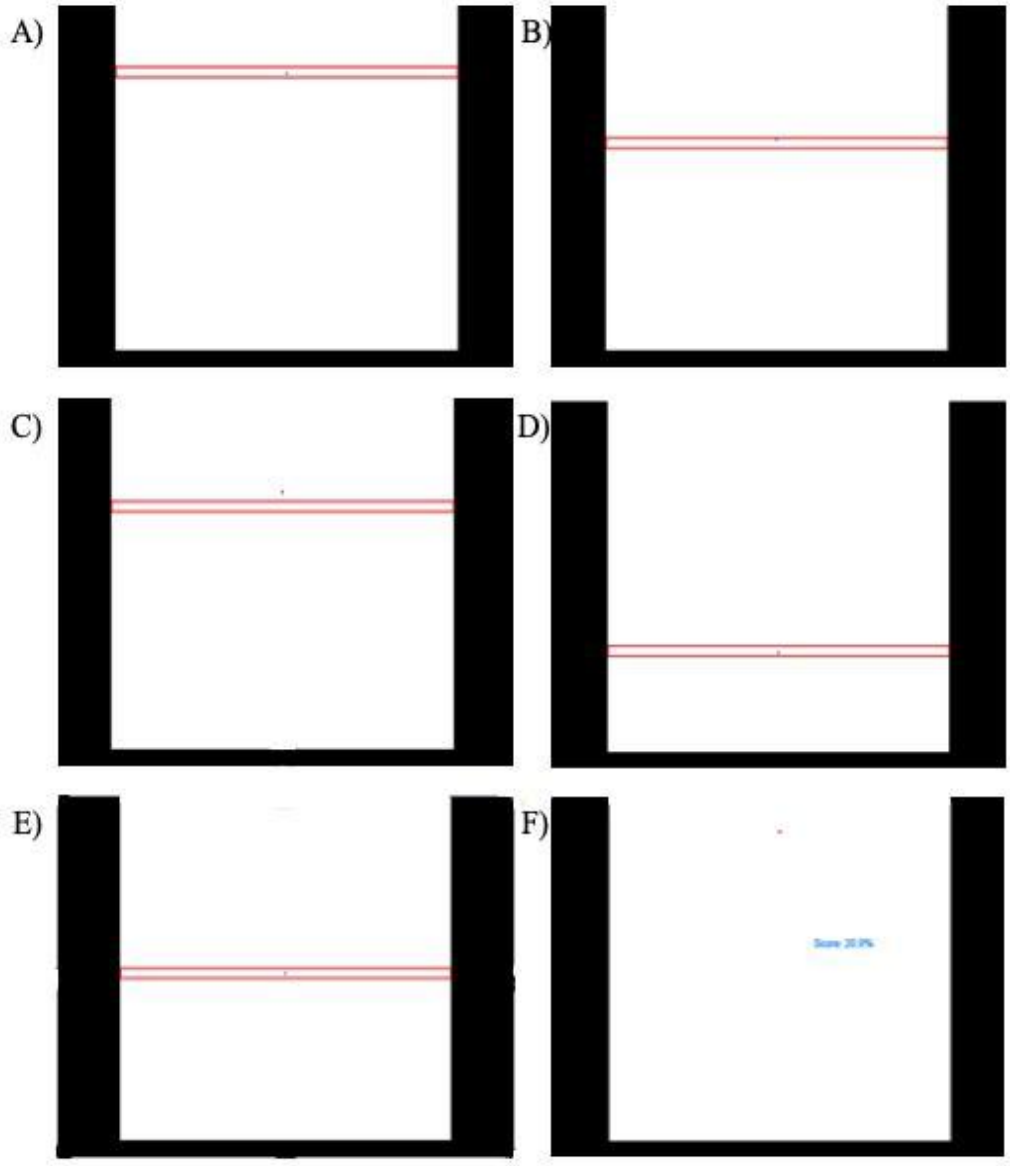

Figure 3. Visuomotor accuracy tracking task as presented on the computer screen. The position of the targets for the acquisition trials was A) 200 pixels B) 400 pixels C) 300 pixels D) 700 pixels E) and 500 pixels. F) The percentage of time the particip

The first familiarization trial consisted of 4 targets each visible for 2 s (~5 seconds in total). The targets were at 800-, 100-, 800- and 100 pixels, respectively. The second familiarization trial consisted of 15 targets. After the familiarization trials and between every other trial there was a 2 min break.

The baseline test and acquisition trials all started and ended with a target at 800 pixels. These two targets were disregarded in the data analysis of the VATT trials. The baseline test consisted of 25 targets (~1 minute in total) being positioned in the same sequence for all the participants. The acquisition phase consisted of a total of 6 trials of training. The targets were presented in a series of 5 and each of the 6 acquisition trials consisted of 20 series equal to 102 targets (~4 min). The sequence consisted of targets positioned at the given order of 200-, 400-, 300, 700- and 500 pixels, which is equivalent to an applied force of 6.2 N, 4.7 N, 2.3 N, 5.4 N and 3.9 N. To avoid participant from having effects of fatigue there was a 2-minute break between each trial.
The second session occurred 12 hours after the beginning of the first session, where the participants performed a retention test with the same sequence of targets as the baseline test and a plateau test used to investigate if the participants had reached a plateau in their performance.

Data analysis

A participant in the control group was excluded because the participant had worse sleep than the participants in the disturbed sleep group. The participant woke up more than 15 times and had less than 3 hours of sleep during the night between the two sessions. Shapiro-Wilks tests were used to test for normality. If the Shapiro-Wilks tests had $p < 0.05$ for sleep time from actigraphy, results from Stanford sleepiness scale measured at the two sessions and data from the sleep diary (sleep time, number of awakenings, sleep quality and function during the day), then independent *t*-tests were used to investigate for differences between the groups, otherwise Mann-Whitney U tests were used. Another two-way repeated measures Analysis of variance (ANOVA) was used to investigate differences in performance of VATT across the baseline test, training block 1-6, Retention and the plateau test with regards to groups. The assumption of sphericity was accepted. Post-hoc Bonferroni corrections were used to investigate which trials differed from each other. Furthermore, a two-way repeated measures ANOVA was used to investigate if there were any difference in the change of the two groups´ VATT performance from B6 to the retention test. Significance was accepted at $p < 0.05$.

WASO was calculated with the data from the sleep diary. Pearson correlations were used to test for correlation between WASO of the night before acquisition and improvement from baseline to T6. A Pearson correlation were also used to test for correlation between WASO of the night between acquisition and retention and the difference between T6 and retention. Values are presented as mean ± standard deviation unless otherwise specified.

Results

The results of the Shapiro-Wilks tests used on the sleep data are displayed in table 1. The table also illustrates the p values for the *t*-tests and the Mann-Whitney U tests. There were significant differences between the groups at the night after acquisition for the assessed number of times participants woke up and the assessed sleep quality. The participants in the disturbed sleep group woke up an average of 7.2 times more ($p < 0.001$) and assessed the sleep quality 1.7 points ($p = 0.002$) worse than the control group. There was also a significant difference between the two groups assessments of sleepiness at the second session ($p = 0.021$). The disturbed sleep group were 1.1 points higher on the Stanford sleepiness scale. There were no significant differences for any of the other sleep data (all p's ≥ 0.200).

Table 1. Data from the participants sleep diaries, Stanford sleepiness scale and actigraphy from the watches. Results from the statistic tests made with the sleep data are also illustrated. All significant values are marked with. Data from the participants sleep diary are marked with a ●. C and DS is abbreviations of the control group and the disturbed sleep group, respectively.*

Measure	Control	Disturbed Sleep	Shapiro-Wilks test	T-Test/Mann-Whitney U test
Night before acquisition				
Hours slept●	7.5 ± 2.2	6.9 ± 1.1	C: $p = 0.469$ DS: $p = 0.688$	$p = 0.533$
No. of times woken up●	0.9 ± 1.1	1.6 ± 1.0	C: $p = 0.038$* DS: $p = 0.208$	$p = 0.200$
Sleep qualtity●	3.9 ± 1.4	3.4 ± 0.7	C: $p = 0.036$* DS: $p = 0.008$*	$p = 0.236$
Day of acquisition				
Function during the day●	4.0 ± 0.8	4.1 ± 0.8	C: $p = 0.093$ DS: $p = 0.055$	$p = 0.771$
Stanford sleepiness scale	2.4 ± 1.1	2.6 ± 0.7	C: $p = 0.366$ DS: $p = 0.001$*	$p = 0.741$
Night after acquisition				
Actigraphy (hours slept)	7.6 ± 1.8	6.8 ± 1.7	C: $p = 0.139$ DS: $p = 0.359$	$p = 0.369$
Hours slept●	7.6 ± 0.7	7.6 ± 0.3	C: $p = 0.027$* DS: $p = 0.376$	$p = 0.277$
No. of times woken up●	1.9 ± 1.5	9.1 ± 2.3	C: $p = 0.002$* DS: $p = 0.012$*	$p < 0.001$*
Sleep qualtity●	3.5 ± 1.1	1.8 ± 0.7	C: $p = 0.120$ DS: $p = 0.028$*	$p = 0.002$*
Day of Retention				
Stanford sleepiness scale	2.1 ± 1.1	3.2 ± 1.1	C: $p = 0.037$* DS: $p = 0.112$	$p = 0.021$*

The two groups VATT results are illustrated in figure 4. Shapiro-Wilks tests showed that the data for VATT was normally distributed for all trials. The assumption of sphericity was met so no corrections of degrees of freedom was used. The ANOVA for all the trials (Baseline, T1-T6, retention and PT) showed no significant interaction between groups and time [$F_{(8,120)} = 0.842$, $p = 0.568$] or a main effect of group [$F_{(1,15)} = 0.096$, $p = 0.76$]. It showed a significant main effect of time ($F_{(8,120)} = 43.738$, $p < 0.001$). The Significant differences between trials found with the post hoc Bonferroni is illustrated in figure 4. The post hoc showed a significant improvement across group from baseline going through T1-T3 (all $p \leq 0.013$). The improvement from baseline to T3 was 26.4 ± 12.0 % of baseline. The post hoc showed no differences across the groups from T3-T5 (all p's > 0.35). The participants across groups significantly improved VATT from T5 to T6 with 6.0 ± 4.7 % of T5 ($p < 0.001$). The participants improved significantly from Baseline to T6 with 36.4 ± 12.1 % of baseline ($p < 0.001$). Their VATT performance significantly worsened from T6 to retention with -8.1 ± 8.5 % of T6 ($p = 0.002$) and was improved from T6 to PT with 3.5 ± 5.9 % of T6 ($p = 0.031$). The post hoc also showed a significant improvement in VATT across both groups from retention to the plateau test ($p < 0.001$). The participants improved across groups from Retention to the plateau test with 12.6 ± 6.3 % of retention.

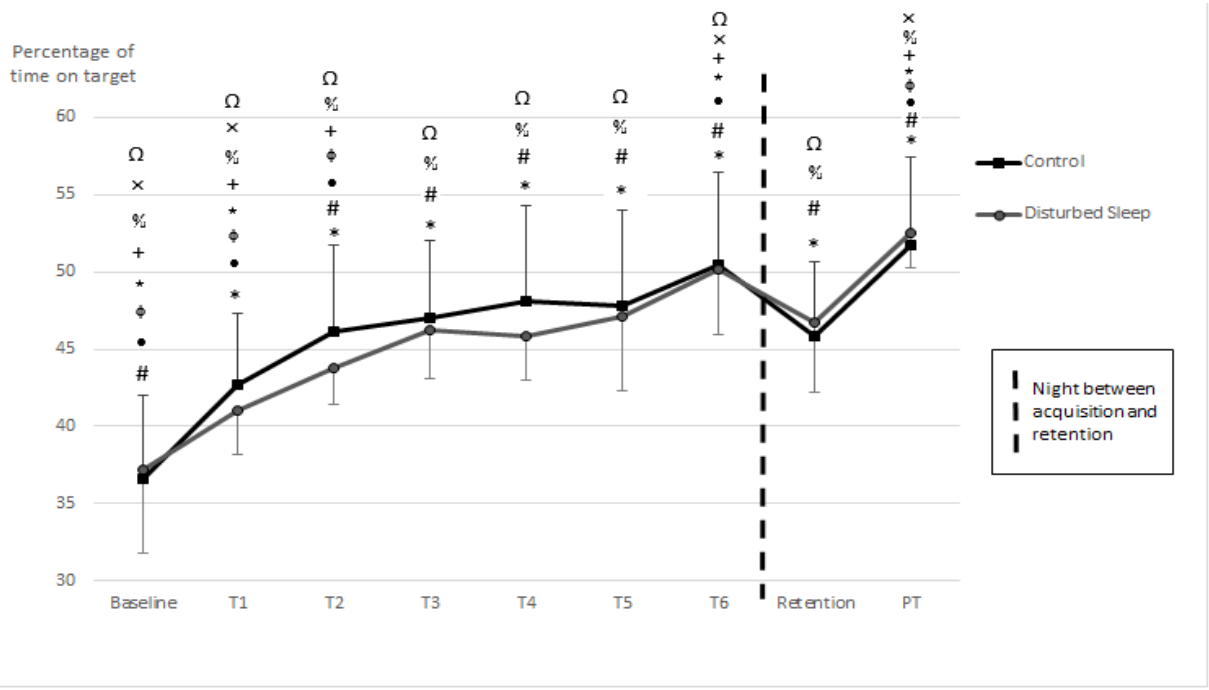

*Figure 4. Illustrates VATT results for both gr groups at the different trials. The error bars going upwards and downwards illustrates the standard deviations for the control group and disturbed sleep group, respectively. There were only significant differences in the main effect of time * indicates significant differences from Baseline. # indicates significant differences from T1. • indicates significant differences from T2. ϕ indicates significant differences from T3. * Indicates significant differences from T4. + indicates significant differences from T5 % indicates significant differences from T6. × Retention. Ω Indicates significant differences from PT.*

The worsening of performance is illustrated for both the disturbed sleep group and the control group in figure 5. The ANOVA for B6 and retention showed no significant interaction between groups and time [$F_{(1,15)} = 0.305$, $p = 0.589$]. There was no significant main effect of group [$F_{(1,15)} = 0.017$, $p = 0.898$]. However, there was a significant main effect of time in VATT between T6 and Retention [$F_{(1,15)} = 13.466$, $p = 0.002$]. The group's performance in VATT between T6 and Retention decreased with -8.93 ± 6.75 % and -6.82 ± 9.99 % of performance at T6 for the control group and disturbed sleep group, respectively (see figure 5).

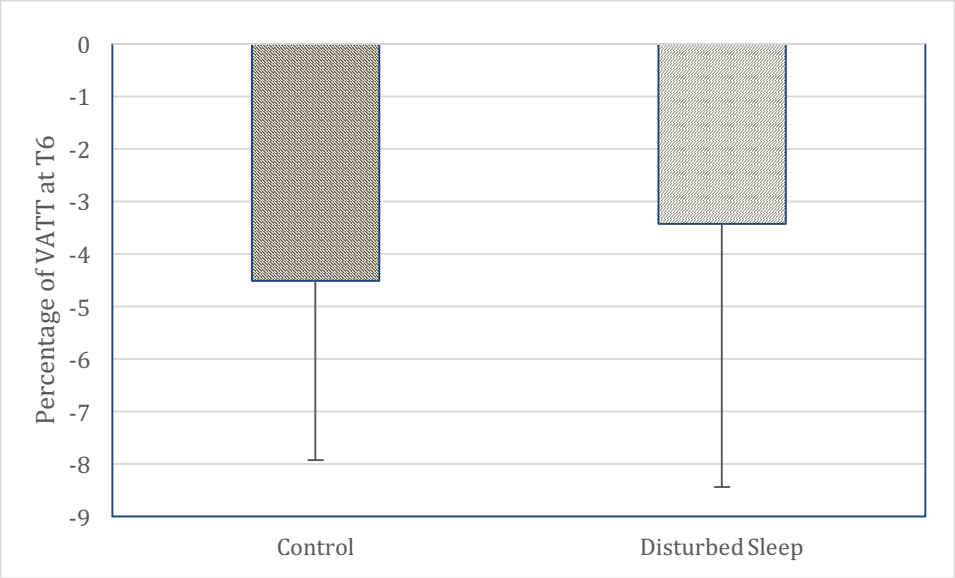

Figure 5. Illustrates the change in VATT from trial 6 to the retention test. The error bars illustrate the standard deviation. The Y axis is percentage from T6 to Retention in percentage of performance from T6.

The Pearson correlation between WASO of the night before acquisition and improvement of VATT from baseline to T6 showed no correlation ($p = 0.59$). The Pearson correlation between WASO of the night between the sessions and the difference between T6 and Retention showed no correlation ($p = 0.66$).

Discussion

The purpose of the present study was to investigate the influence of sleep quality on the consolidation of VATT. The results of the study showed no significant differences between the disturbed sleep group and the control group with regards to acquisition and consolidation of VATT, which suggests the quality of sleep during the night after acquisition does not affect retention of the learned skill. However, this study cannot conclude the long term effects because retention was measured only 12 hours after acquisition. Furthermore, it cannot conclude how several nights of bad sleep would affect the performance and learning of VATT. It could be suggested that bad sleep quality over a single night is not enough to affect the consolidation of VATT. If the participants also had been disturbed in their sleep before the acquisition of VATT then a night of bad sleep could have affected their consolidation-

There were no significant differences between the number of hours and perceived quality of sleep the night before acquisition between the two groups (Table 1). However, the disturbed sleep group had worse perceived quality of sleep and woke up more often during the night between the acquisition session and the retention test than the control group (Table 1). These results and the significant more sleepiness at the second session (Table 1) indicates that the intervention in the disturbed sleep group successfully worsened the quality of their sleep. This verifies the hypothesis that the participants perceived sleep quality is affected by hourly awakenings. This was essential to investigate the influence of quality of sleep on consolidation of VATT as was the purpose of this study.

If the participants had reached a performance plateau at the retention test, it would probably not have been possible to show a difference in consolidation between the two groups. Because if good quality of sleep improved the consolidation of VATT compared to bad sleep quality and they both reached a plateau, it would be improbable to see further improvement of good quality sleep. It seems that the participants reached a performance plateau between trials 3-5 (figure 4) since the post hoc Bonferroni showed no significant difference between these trials. However, this does not seem to be a problem with regards to establishing differences between the two groups, because there was a significant improvement from T5 to T6 which indicates that the participants broke through the plateau at trial 6. Furthermore, the plateau test measured after the retention test shows a significantly improved performance for both groups than the retention test. However, this could possibly be explained by the

differences of sequence in the retention trial compared to those of the acquisition trials and plateau test, which were the same. In the master's thesis by Maes & Nissen (2019), there were no significant differences in performance between the retention test with the same sequence as the one trained and the retention test with a different sequence. This would indicate that the six acquisition trials improves the performance of the task overall and is not specific to the sequence in which the targets appear. The differences in sequences could explain why there was no significant difference between the groups VATT performance from trial 6 to retention. However, there was also no difference between the groups performance from trial 6 to the plateau test, which suggests there is neither a sequence nor a more general skill component which is disrupted by the disturbance of sleep.

The authors of the present study did not find the data from the actigraphy watches used particularly reliable. An example of this was one of the participants who had slept 6.83 hours according to their sleep diary and 4 hours according to the watch. Furthermore, there were several examples of participants in the disturbed sleep group who, according to their sleep diary, woke up at least seven times in the night between testing sessions like they were supposed to, but according to their watch woke up less than two times. In a study by Mantua et al. (2016), they compared four different actigraphy devices with polysomnography. They found no difference between any of the devices and the polysomnography regarding sleep time. However only one of the devices had a correlation with polysomnography in regard to sleep efficiency and it was found to be weak. None of the four devices in the study were the type that was used in the present study. This is the reason why there is not a lot of emphasis on the data from the actigraphy watches in the present study.

The study by Borich and Kimberley (2011) and the master's thesis from Copenhagen University (Maes & Nissen, 2019) did not find a correlation between sleep and motor skill performance or learning. Both these studies investigated the VATT just like the present study which did not see a difference on consolidation of the task between a sleep disturbed group and a control group. This suggests that sleep quality does not influence the consolidation of VATT. However, it should be mentioned that the study of Borich and Kimberley (2012) did see positive correlations between the number of hours the participants slept and their consolidation of VATT. Studies which have investigated the effect of sleep on a finger tapping task have shown positive correlations between sleep and the consolidation of the task (Lee et al., 2012; Fisher et al., 2002; Fisher et al., 2005; Landry et al., 2015; Walker et al.,

2002; Genzel et al., 2011). Studies in other tasks have also shown positive effects from sleep (Allen, 2012; Genzel et al., 2012; Al-Sharman & Siengsukon, 2013). This could indicate that the effect of sleep on consolidation of motor tasks is dependent on the task. The results of the present study showed no correlation between WASO of the night before acquisition and the improvements during the acquisition. There was also no correlation between WASO of the night after acquisition and the difference between trial 6 and the retention test. These results give a different conclusion of the influence of sleep on motor learning than those of Appleman et al. (2016), who showed a negative relationship between WASO and the gains during acquisition of a finger tapping task. This could further indicate that the effect of sleep on motor learning is dependent on the task, because other studies with different tasks have seen correlation or effects of sleep on either consolidation or acquisition of the used task.

In the analysis of data, the disturbed sleep group perceived the quality of sleep during the night between the two experimental sessions significantly worse than the control group. That would suggest that the disturbance of sleep was effective for the disturbed sleep group. In a study by Karni et al. (1994), they removed REM and slow wave sleep from participants by waking the participants in these stages. After being awakened, the participants often returned to the stage of non-REM or REM sleep they were in before being woken up. They had to wake the participants between 20 and 60 times to limit the amount of REM and slow wave sleep. This would suggest that the participants in the disturbed sleep group in the current study likely did not have different distributions of sleep stages. A disruption of sleep aiming at specific sleep stages might show a worse consolidation of VATT.

A different result could possibly have occurred if the retention trial was longer or there were several in a row, because a longer test time after low quality sleep has shown to decrease motor performance (Loh et al., 2004). A study by Loh et al. (2004), showed that when making a longer retention test on sleep deprived participants, there was a performance decrease in a ten-minute retention test of a psychomotor vigilance task. The Loh et al. (2004), study showed that the performance progressively decreased as time went on. The participants in the present study were only tested for a one-minute retention test and a four-minute plateau test. If the tests in the second session would have included six trials like the acquisition, it could possibly have shown a difference between the participants in the disturbed sleep group and the control group. According to Loh et al. (2004), when sleepiness increases, alertness and vigilance will deteriorate, and motor skill performance will decline. However, it might be

suggested that the level of vigilance or arousal can be sustained by the participants in the sleep disturbed group for the tests in the second session in this study, because of the relatively short testing time. According to Oxendine (1970), for an individual to perform at their best they have to be in the right emotional arousal stage, which can be affected by the loss of or lack of sleep.

Conclusion

The findings of this study suggest that the quality of sleep does not seem to have an effect on the consolidation of VATT. However, the disturbed sleep period was only one night and therefore does not provide information on longer periods with disturbed sleep. These findings suggest that the effect of sleep on consolidation of motor skills is dependent of the skill. The present study showed that sleep quality is affected by awakening once an hour while sleeping.

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