Sleep and Automaticity in Word Learning and Numerical Cognition

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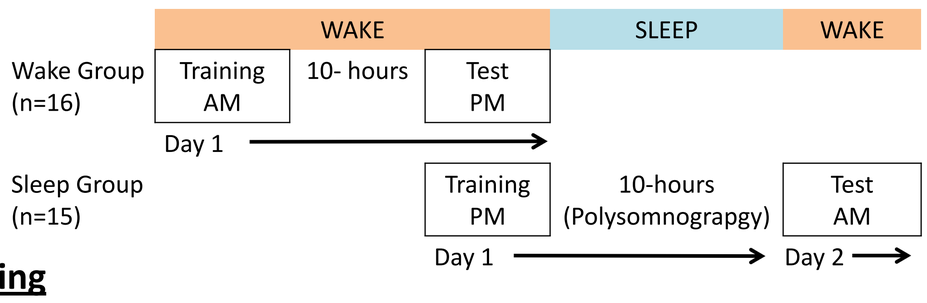
Objectives

Two experiments investigated whether sleep benefits memory for new words[1,2] and numerals by examining automaticity in the activation of meanings, using **Size Congruity Effects (SCEs)** and **Semantic Distance Effects (SDEs)** in a second-language learning paradigm[3,4]. SCEs occur when participants compare physical(font) or semantic size of written-word pairs: correct responses are faster when both dimensions are congruent (e.g., BEE-COW, 1-9) than incongruent (e.g., BEE-COW, 1-9). SDEs involve swifter semantic size judgements for distant items (e.g., BEE-COW, 1-9) compared with closer items (e.g., DOG-COW, 8-9).

- We predicted participants who slept before testing would show stronger SCEs and SDEs for the new items than participants remaining awake, which is a marker of greater automaticity in activating meanings.
- Based on existing literature[5], we also hypothesized that differences in automaticity would be related to components of sleep, namely slow-wave sleep (SWS) and sleep spindle activity.

Methods

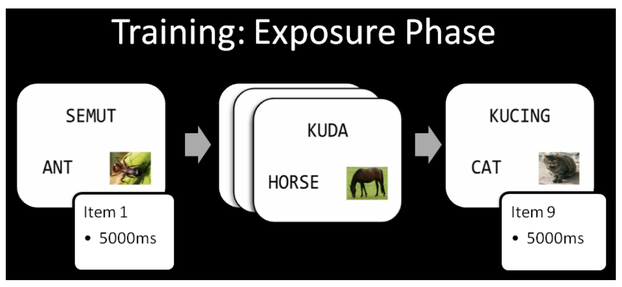
Experiment 1: Word Learning



Training

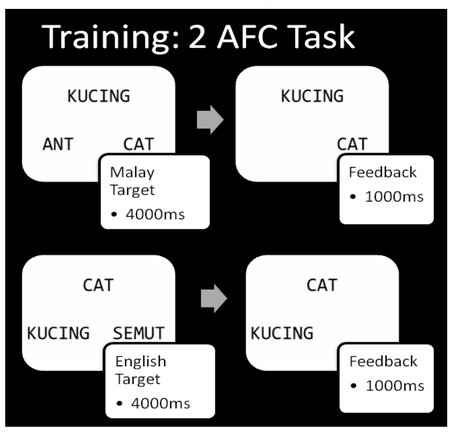
i) Exposure

Participants learned 9 new Malay words referring to different sized animals by associating them with existing English words.



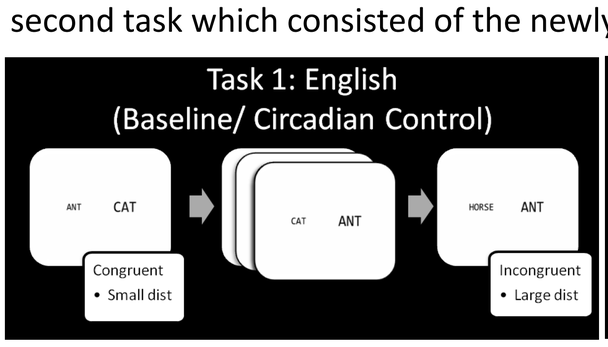
ii) 2 Alternative Forced Choice Task

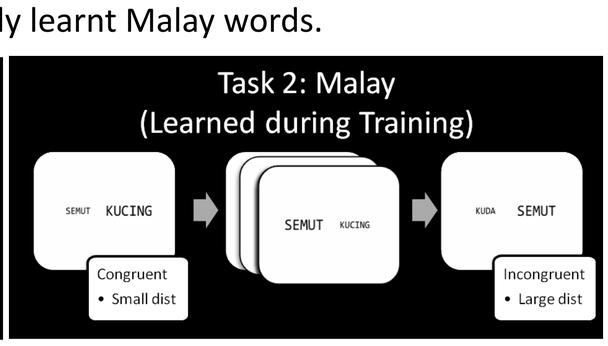
Participants had to select the item with the same meaning as the target. Feedback was always given



Test

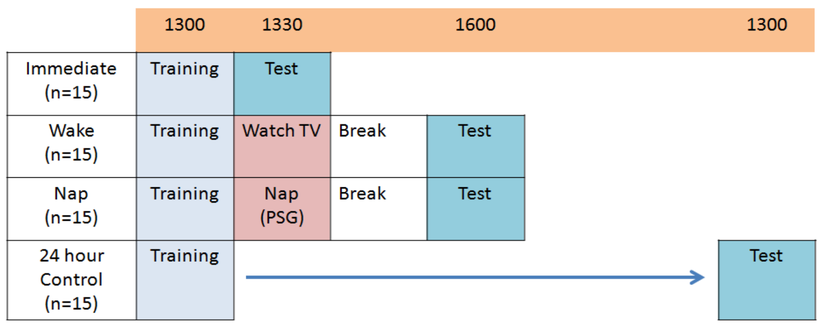
- Participants saw item-pairs differing in small or large semantic (animal size) distance, where relative physical(font) and semantic sizes of were either congruent or incongruent.
- Participants had to select the semantically larger animal in both the first task which consisted of English stimuli to control for circadian effects, and the second task which consisted of the newly learnt Malay words.





Experiment 2: Numerical Cognition

- Participants learned 9 novel numerals instead of words
- Manipulation of experimental stimuli during training and the test session was similar to Experiment 1.



Results

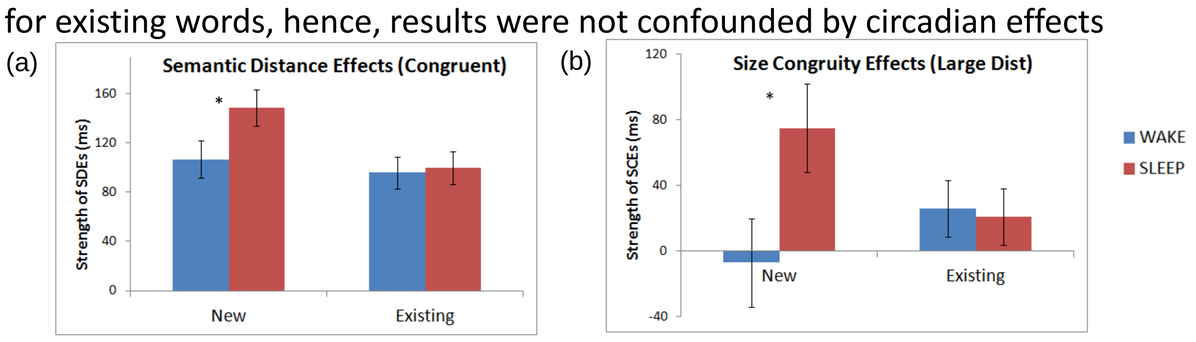
Experiment 1. Size Congruity Effect & Semantic Distance Effect

New Words

- Both groups showed a main effect of Distance ($p < .001$) for all congruent item-pairs. **The sleep group also experienced significantly greater SDEs ($p = .024$) compared to the wake group** for the above item-pairs.
- For items with large distances, **the sleep group showed greater SCEs than the wake group ($p = .025$)**. In addition, the main effect of Congruity was experienced by the sleep ($p = .017$) but not the wake group ($p > .05$).

Existing Words

- There were no equivalent differences (all p's > .05) between wake/sleep groups for existing words, hence, results were not confounded by circadian effects



Strength of Automaticity Effects: (a) Semantic Distance Effects, (b) Size Congruity Effects. Error bars indicate ± standard error.

Experiment 1. Sleep Polysomnography (PSG)

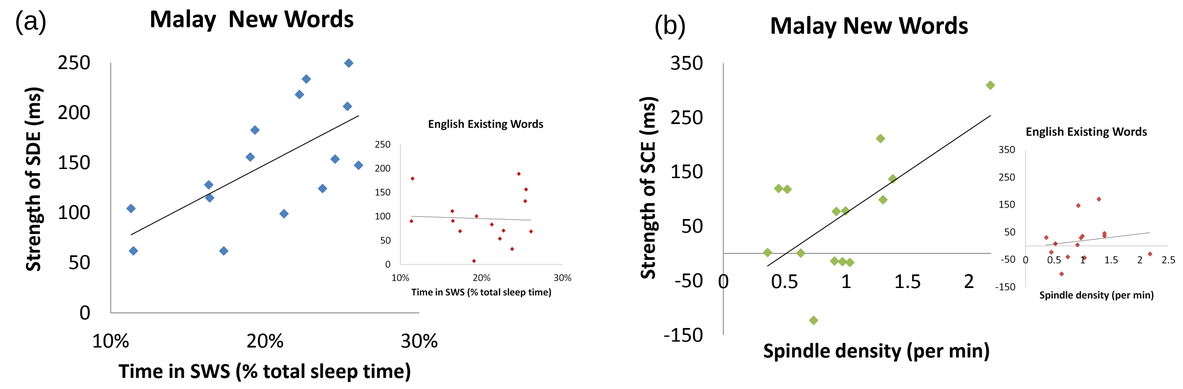
Time spent in slow wave sleep (SWS) was associated with:

- Stronger SDEs for new Malay words : $r = .66$, $p = .028$
- No correlation for English words: $r = -.05$, $p = 1.0$

Sleep spindle density (per min) was associated with:

- Stronger SCEs for new Malay words : $r = .68$, $p = .020$
- No correlation for English words: $r = .02$, $p = 1.0$

Significance levels **remained unchanged** when controlling for spindle density in the SWS analysis and vice versa.



Correlation between Strength of Automaticity Effects and PSG: (a) Semantic Distance Effects, (b) Size Congruity Effects.

Experiment 2

New and Existing Numerals

- All groups showed a main effect of Distance ($p < .001$) and Congruity ($p < .001$).
- There were no significant interactions between wake/sleep groups and SCEs/SDEs (all p's > .05).

Conclusions

- Experiment 1 supports our prediction that the sleep group would show stronger SCEs and SDEs for newly learnt words than the wake group. There were no equivalent findings for English words, indicating that results were not affected by circadian confounds.
- Experiment 2 suggests that the effects of sleep on learning is domain specific; to words but not numerals. Relationships between new and existing numerals may have been more strongly encoded during training than relationships between words, as there are more existing competitor words in each size group.
- Hence, findings support existing literature that the benefit of sleep is greater for weakly encoded items[6].
- Our results also imply that sleep plays an important role in word learning by enhancing automaticity of processing semantic meanings.
- Correlations between PSG and behavioural data further suggests that greater time spent in slow wave sleep and increased spindle activity are both uniquely associated with greater automaticity of processing new word meanings.

References

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