

# **DIFFERENTIAL EFFECT OF FAST AND SLOW SLEEP SPINDLES ON OVERNIGHT IMPROVEMENT IN AN EXPLICIT MEMORY TASK**

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# Sleep and memory consolidation

- Müller and Pilzecker (1900): New memories consolidate slowly over time (“memory consolidation”).
- Jenkins and Dallenbach (1924): Sleep has a role in consolidating memories.

## **Types of “memory“**

- **Declarative (explicit) memory**
- **Procedural (implicit) memory**
- **Perceptual memory**
- **Classical and operant conditioning**
- **Priming**

## **Types of “sleep“**

- **NREM-Sleep**
  - **Macrostructure (i.e. sleep stages)**
  - **Microstructure (e.g. sleep spindles)**
- **REM-sleep**
  - **phasic vs. tonic REM**
  - **REM microstructure (e.g. sawtooth-waves)**

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# Sleep spindles and memory consolidation (1)

- During the occurrence of sleep spindles, there is an increased amount of transfer of information between the hippocampus and neocortex— „hippocampal replay“ (*Buszaki 1996, Sirota et al. 2003*)
- There is a close temporal relationship between high-frequency hippocampal oscillations („ripples“) and cortical sleep spindles (*Siapas & Wilson 1998*)
- On a cellular level, sleep spindles induce optimal conditions for neuronal plasticity (*Sejnowski & Destexhe 2000*).

## Sleep spindles and memory consolidation (2)

- In a night following a learning experiment, sleep spindles occur with a higher prevalence as compared to a control condition (*Gais et al. 2002*).

*Learning-dependent increases in sleep spindle density.  
J Neurosci. 2002 Aug 1;22(15):6830-4.*

- Changes in sleep spindle density correlate significantly with successful memory encoding (*Schabus et al. in press*).

*Sleep spindles and their significance for declarative memory consolidation. Sleep. in press)*

## Methods:

24 healthy subjects (12 f / 12 m ) aged between 20 und 29 years

- Adaptation night and screening for sleep disorders
- 1 week later: learning or control condition (cross-over design):

***encoding*** – ***retrieval 1*** – ***polysomnography*** – ***retrieval 2***

- 1 week after learning condition:

***retrieval 3***

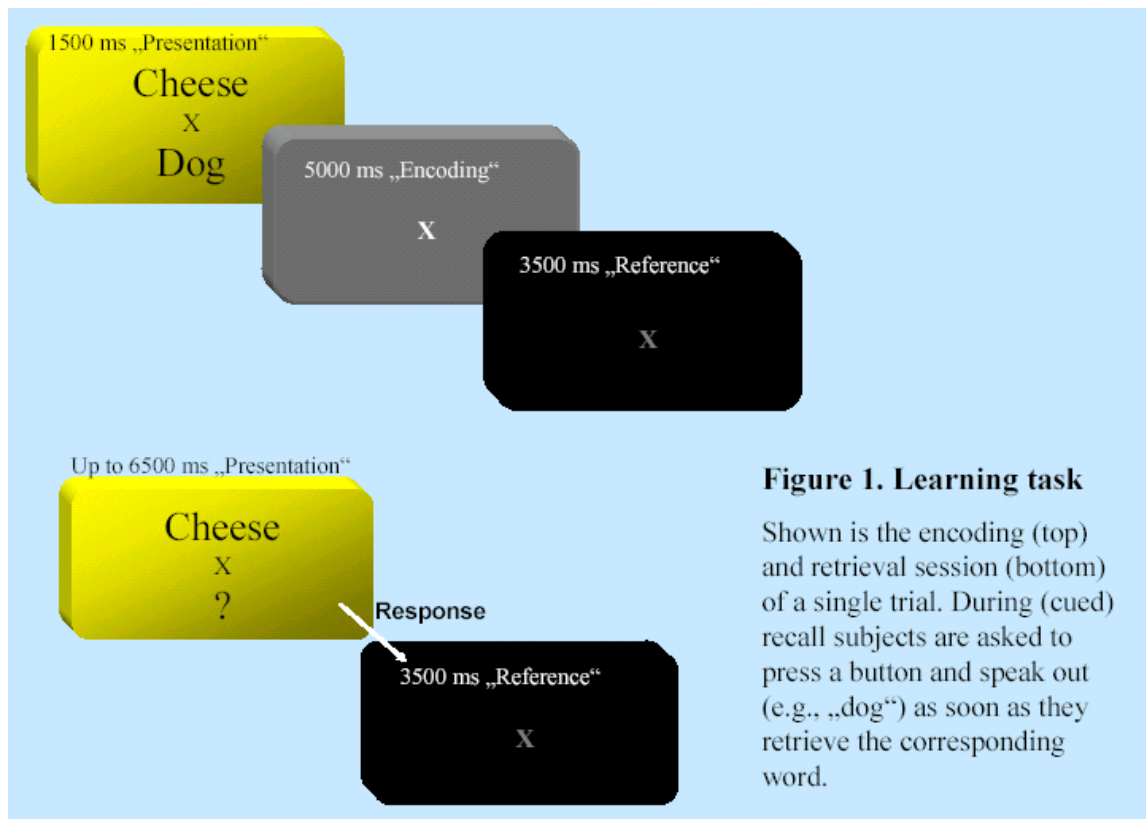
# Learning Task:

Word Pair Association:

160 word pairs, presented twice

Total duration of *encoding*: 60 minutes

***Encoding:***



**Figure 1. Learning task**

Shown is the encoding (top) and retrieval session (bottom) of a single trial. During (cued) recall subjects are asked to press a button and speak out (e.g., „dog“) as soon as they retrieve the corresponding word.

***Retrieval:***

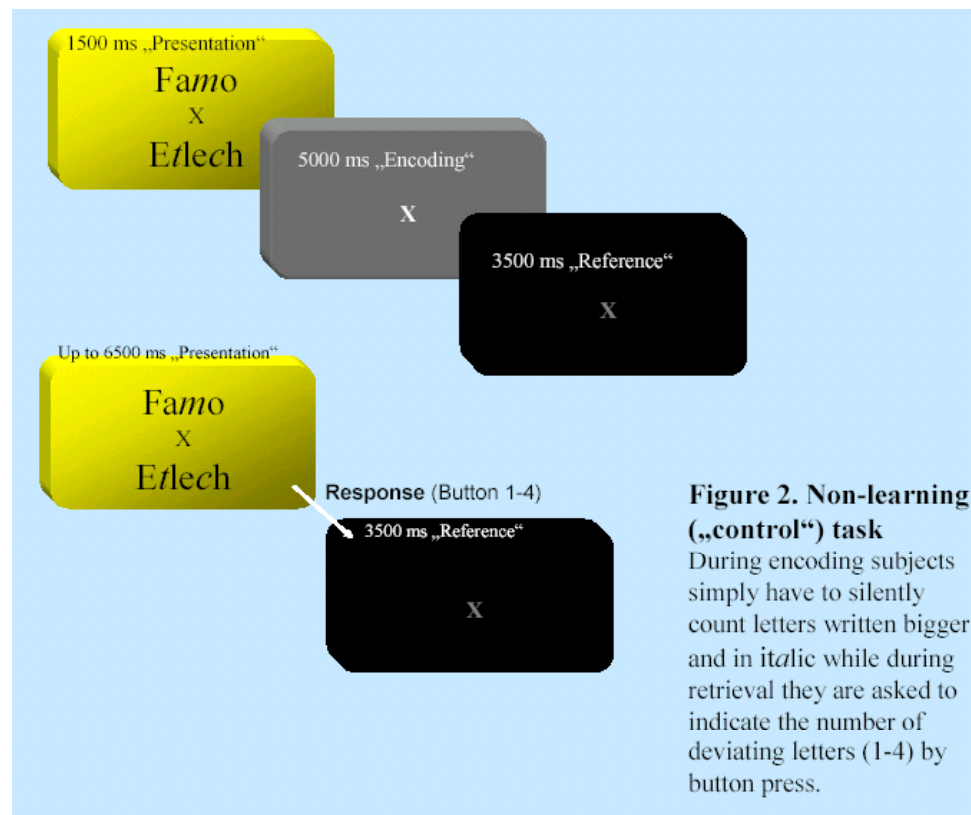
***„cued recall“***

# Control Task:

Pseudo word pairs (no intentional learning):

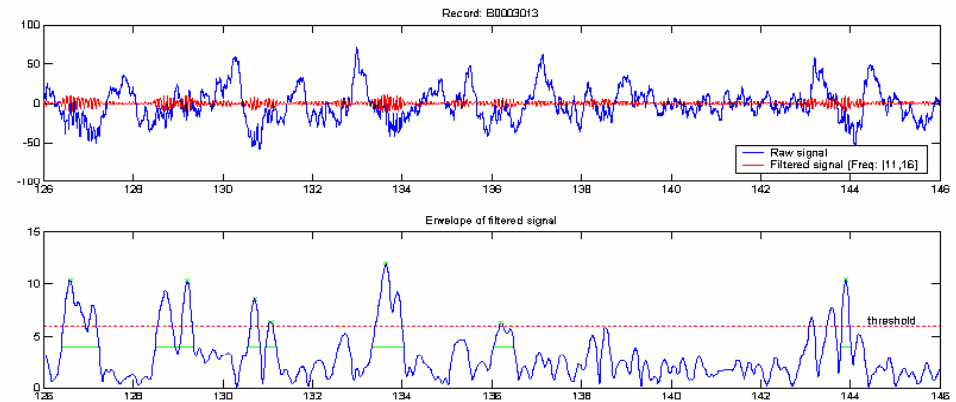
160 pseudo word pairs, presented twice

Total duration of *encoding*: 60 minutes



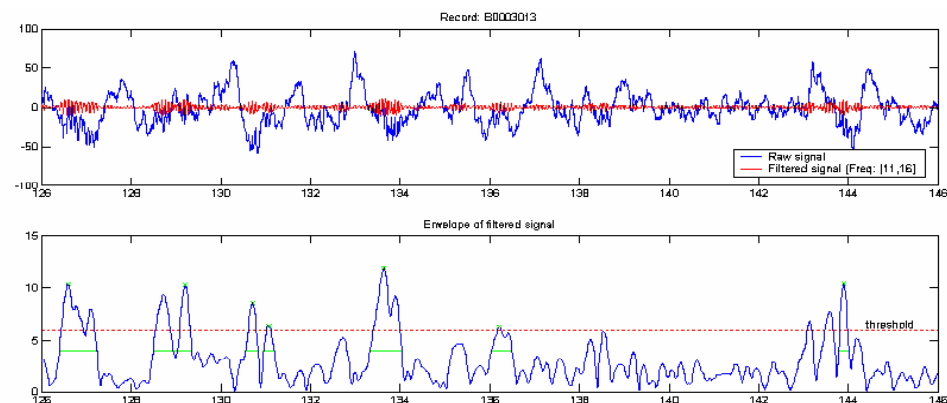
# Automatic sleep spindle detection

(1) Identification of „possible“ spindle episodes based on band pass filtering

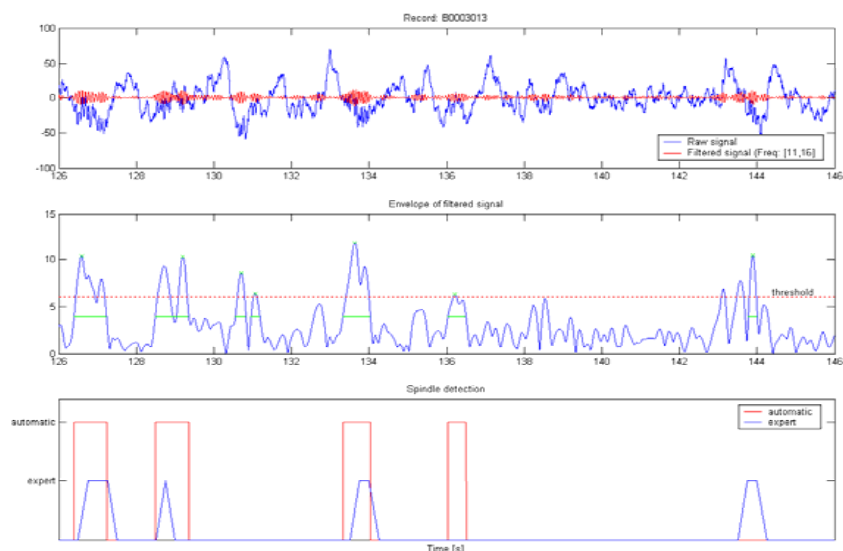


# Automatic sleep spindle detection

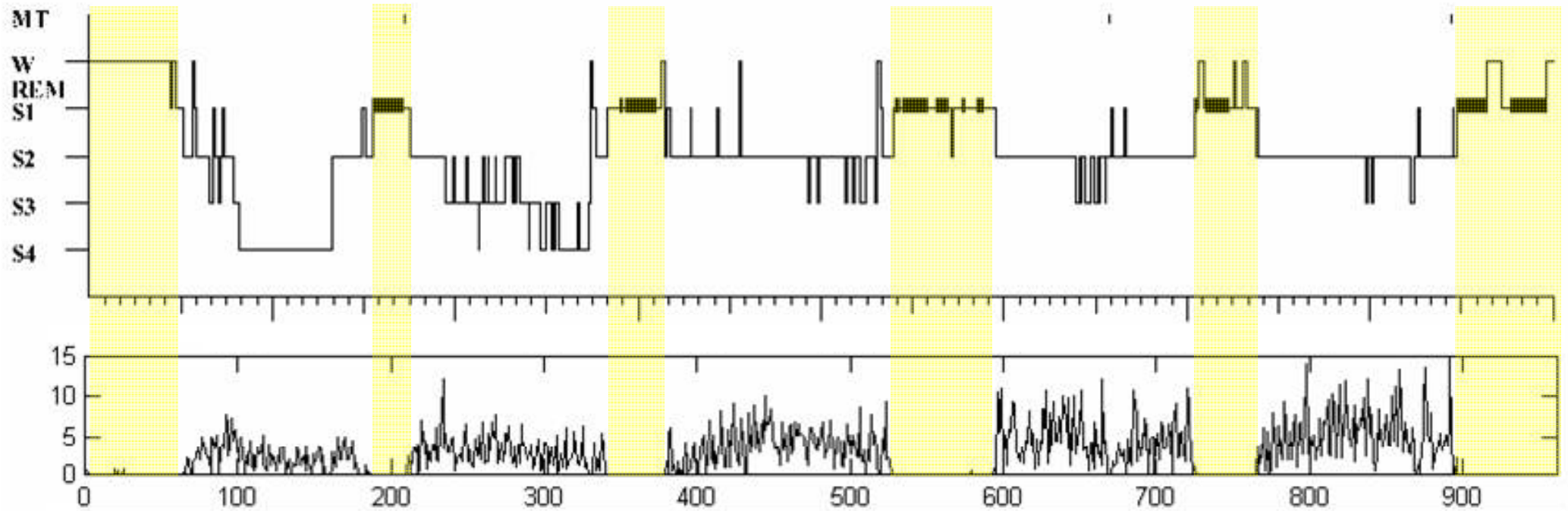
**(1) Identification of „possible“ spindle episodes based on band pass filtering**

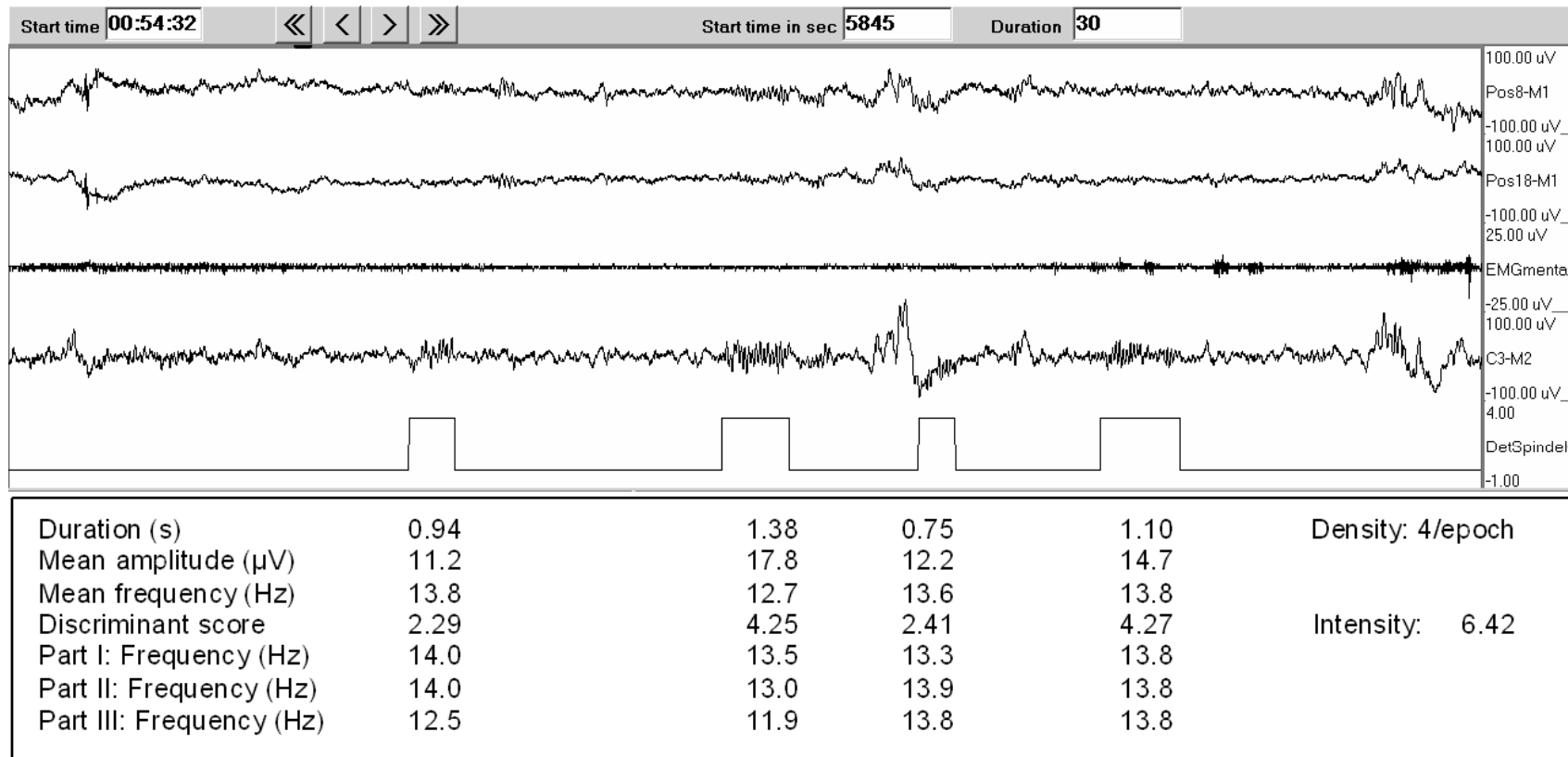


**(2) Spindle detection by means of a linear discriminate analysis using 5 log-transformed features (spindle duration and mean amplitudes in 4 frequency bands: spindle, theta, alpha, and fast beta)**



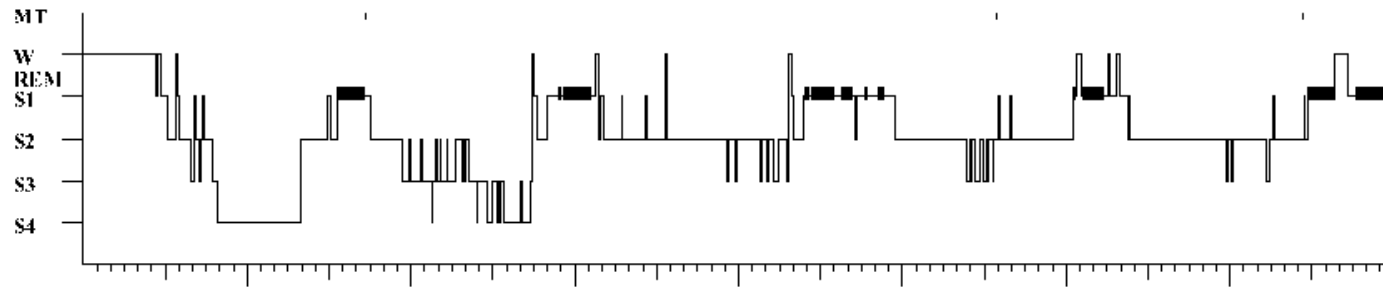
# Spindle Intensity per 30-s epoch



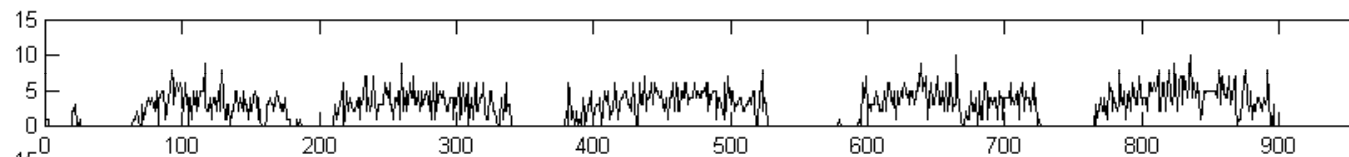


**Example of the Siesta spindle detector. In the upper part, a 30-s epoch shows two EOG (Pos8-M1 and Pos 18-M1), one EMG (mental) and one EEG (C3-M2) channels, together with a channel marking the detected sleep spindle episodes (healthy control, female, 26 years, stage-2 sleep).**

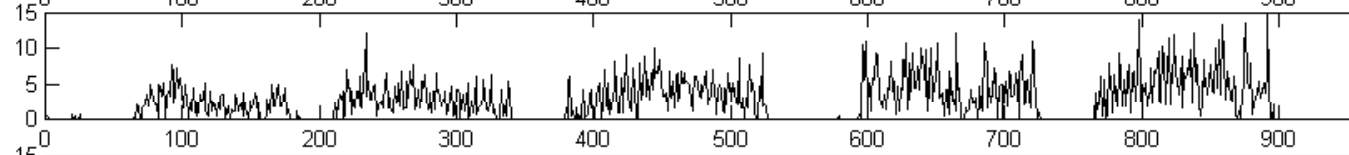
# Density and intensity for fast and slow spindles



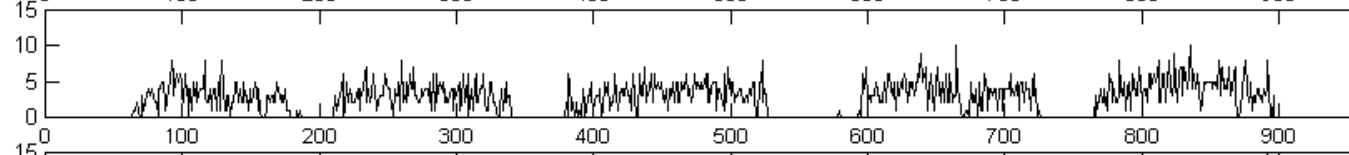
Hypnogram



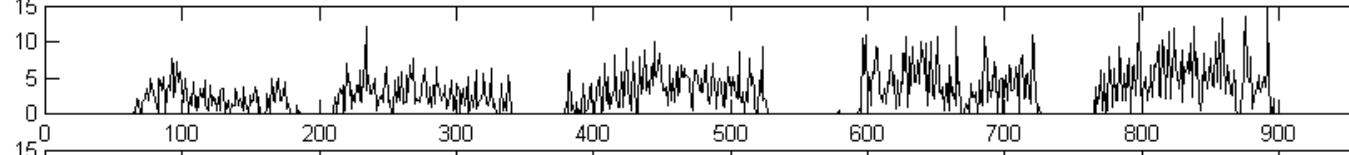
spindle density



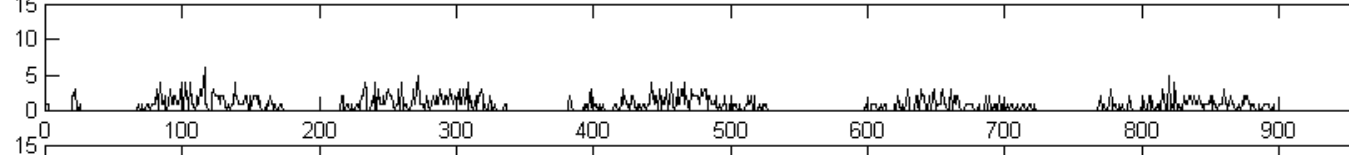
spindle intensity



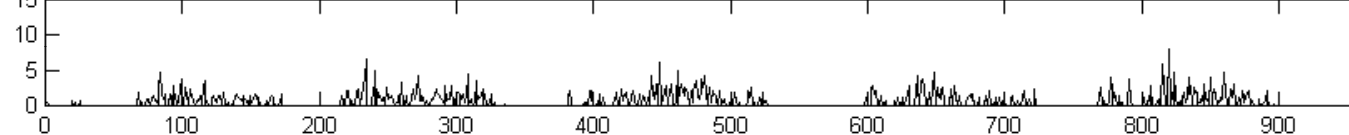
fast spindle density



fast spindle intensity



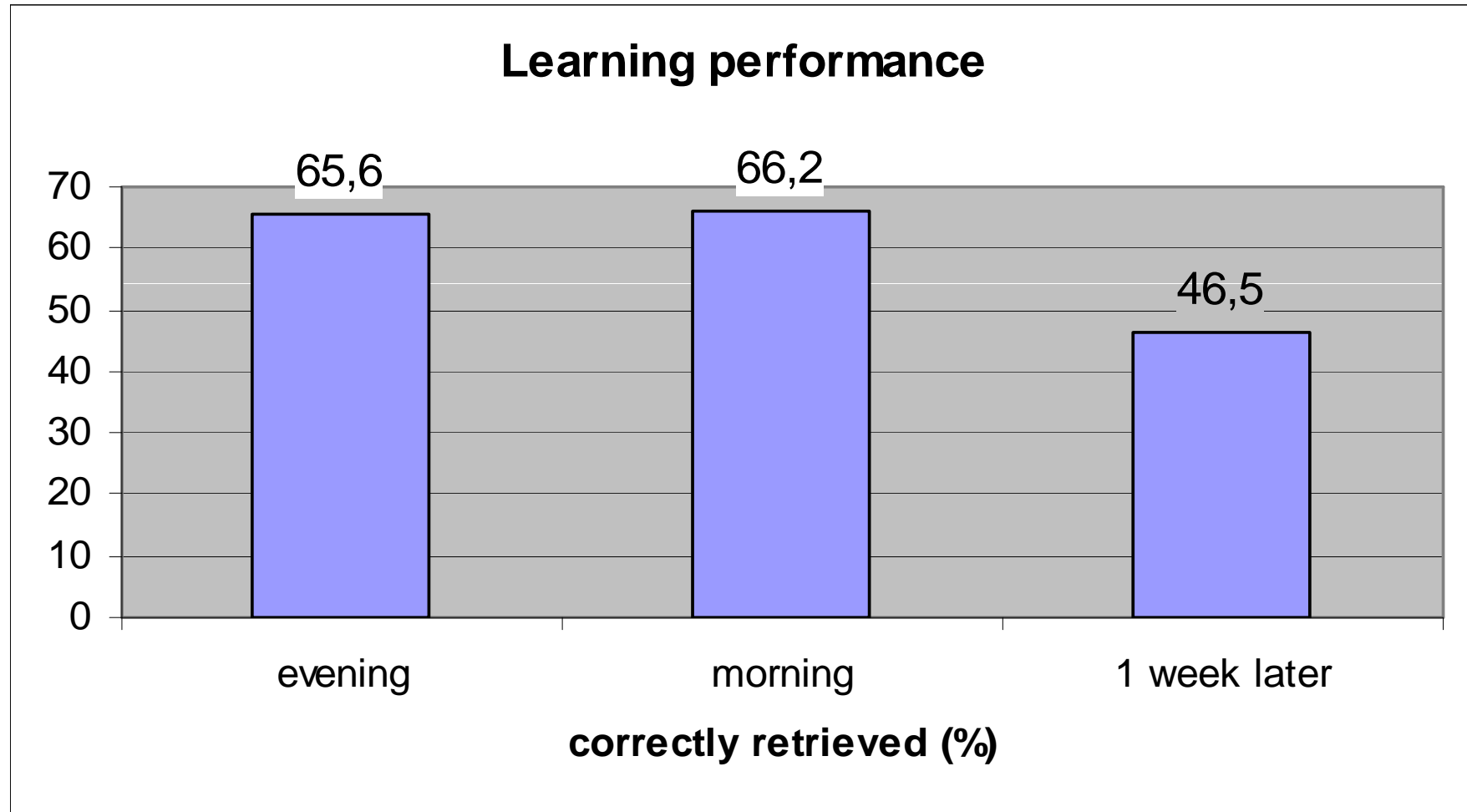
slow spindle density



slow spindle intensity

per 30 s epochs

# Results



	Experimental Night mean ( $\pm$ SD)	Control Night mean ( $\pm$ SD)
Sleep Efficiency Index	85.68 ( $\pm$ 14.89)	90.88 ( $\pm$ 5.47)
Sleep stage 1 (minutes)	40.85 ( $\pm$ 15.27)	39.19 ( $\pm$ 15.04)
Sleep stage 1 (%)	9.83 ( $\pm$ 4.59)	9.09 ( $\pm$ 3.64)
Sleep stage 2 (minutes)	194.500 ( $\pm$ 39.10)	203.71 ( $\pm$ 34.73)
Sleep stage 2 (%)	45.12 ( $\pm$ 7.56)	46.73 ( $\pm$ 6.76)
Sleep stage 3 (minutes)	43.13 ( $\pm$ 15.17)	40.46 ( $\pm$ 14.20)
Sleep stage 3 (%)	9.86 ( $\pm$ 3.00)	9.27 ( $\pm$ 3.04)
Sleep stage 4 (minutes)	66.15 ( $\pm$ 24.19)	63.83 ( $\pm$ 21.33)
Sleep stage 4 (%)	15.65 ( $\pm$ 6.31)	14.76 ( $\pm$ 4.99)
Sleep stage REM (minutes)	86.25 ( $\pm$ 29.67)	87.88 ( $\pm$ 21.10)
Sleep stage REM (%)	19.55 ( $\pm$ 5.94)	20.15 ( $\pm$ 4.31)

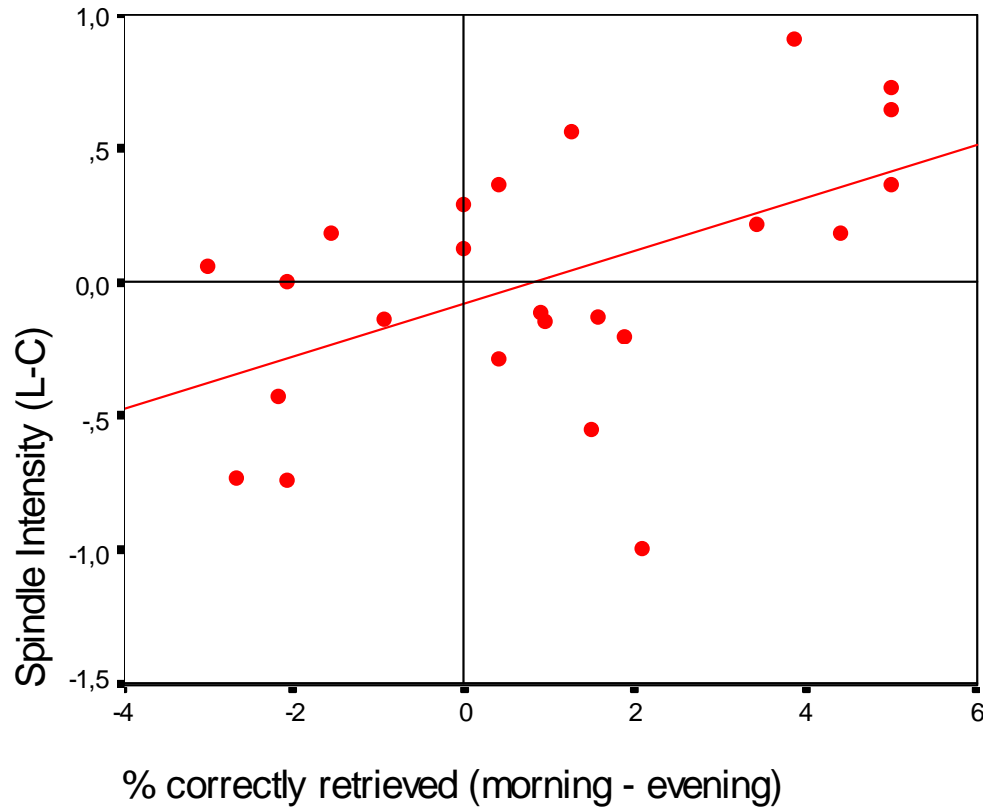
**Sleep efficiency and sleep architecture did not differ significantly in both nights.**

	Experimental Night mean ( $\pm$ SD)	Control Night mean ( $\pm$ SD)
Spindle density /minute stage2	5.15 ( $\pm$ 2.30)	5.17 ( $\pm$ 2.19)
Spindle intensity /minute stage2	5.18 ( $\pm$ 3.88)	5.16 ( $\pm$ 3.78)
Fast spindle density /minute stage 2	4.46 ( $\pm$ 2.07)	4.48 ( $\pm$ 1.79)
Fast spindle intensity /minute stage2	4.60 ( $\pm$ 3.60)	4.56 ( $\pm$ 2.08)
Slow spindle density /minute stage 2	2.16 ( $\pm$ 1.24)	2.22 ( $\pm$ 1.30)
Slow spindle intensity /minute stage2	2.03 ( $\pm$ 1.60)	2.16 ( $\pm$ 1.92)

**Density and intensity for total, fast and slow spindles per minute stage 2 sleep in nights following the experimental and the control condition.**

**Spindle measures did not differ significantly in both nights.**

# Changes in spindle intensity (learning – control night) vs. overnight changes in memory performance

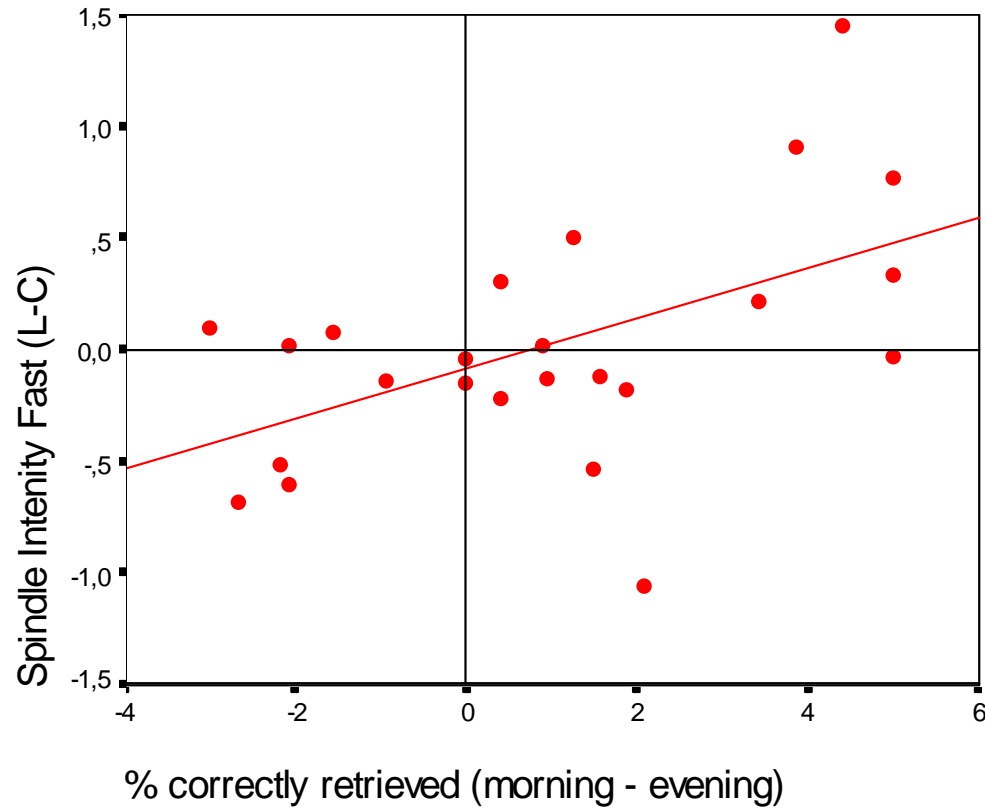


Correlations

		CHANGE	SPI_D
Pearson	CHANGE	1,000	,522**
Correlation	SPI_D	,522**	1,000
Sig.	CHANGE	,	,009
(2-tailed)	SPI_D	,009	,
N	CHANGE	24	24
	SPI_D	24	24

\*\* . Correlation is significant at the 0.01 level (2-tailed).

# Changes in fast spindle (>13 Hz) intensity (learning – control night) vs. overnight changes in memory performance

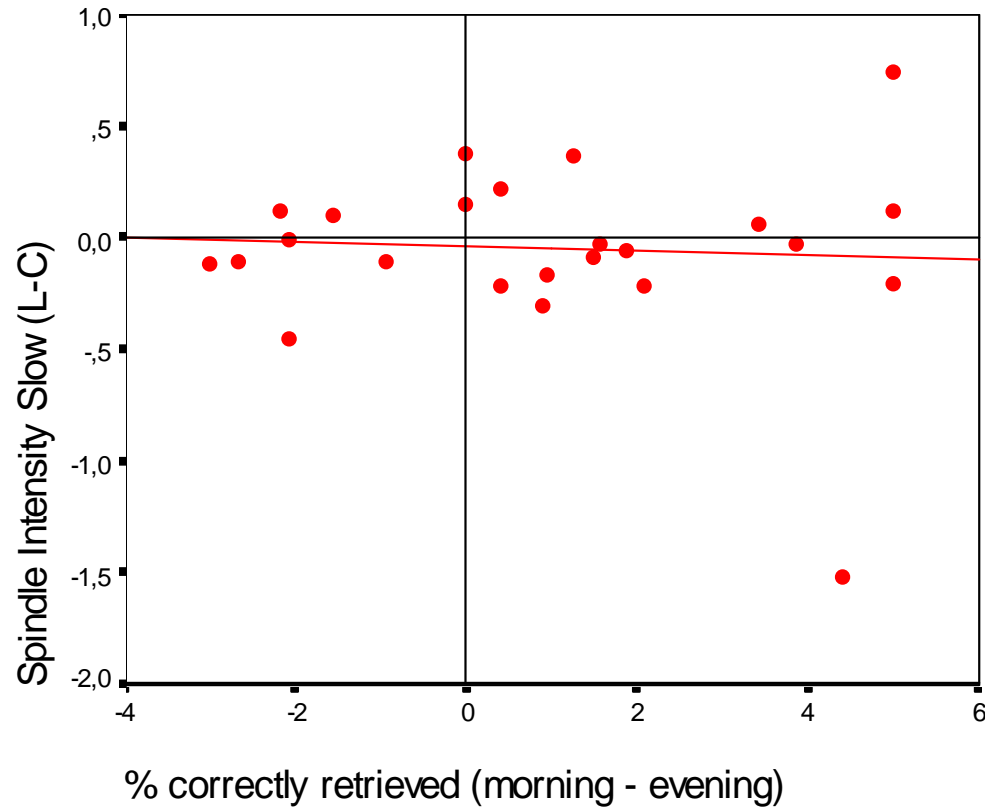


Correlations

		CHANGE	SPIF_D
Pearson Correlation	CHANGE	1,000	,530**
	SPIF_D	,530**	1,000
Sig. (2-tailed)	CHANGE	,	,008
	SPIF_D	,008	,
N	CHANGE	24	24
	SPIF_D	24	24

\*\* . Correlation is significant at the 0.01 level (2-tailed).

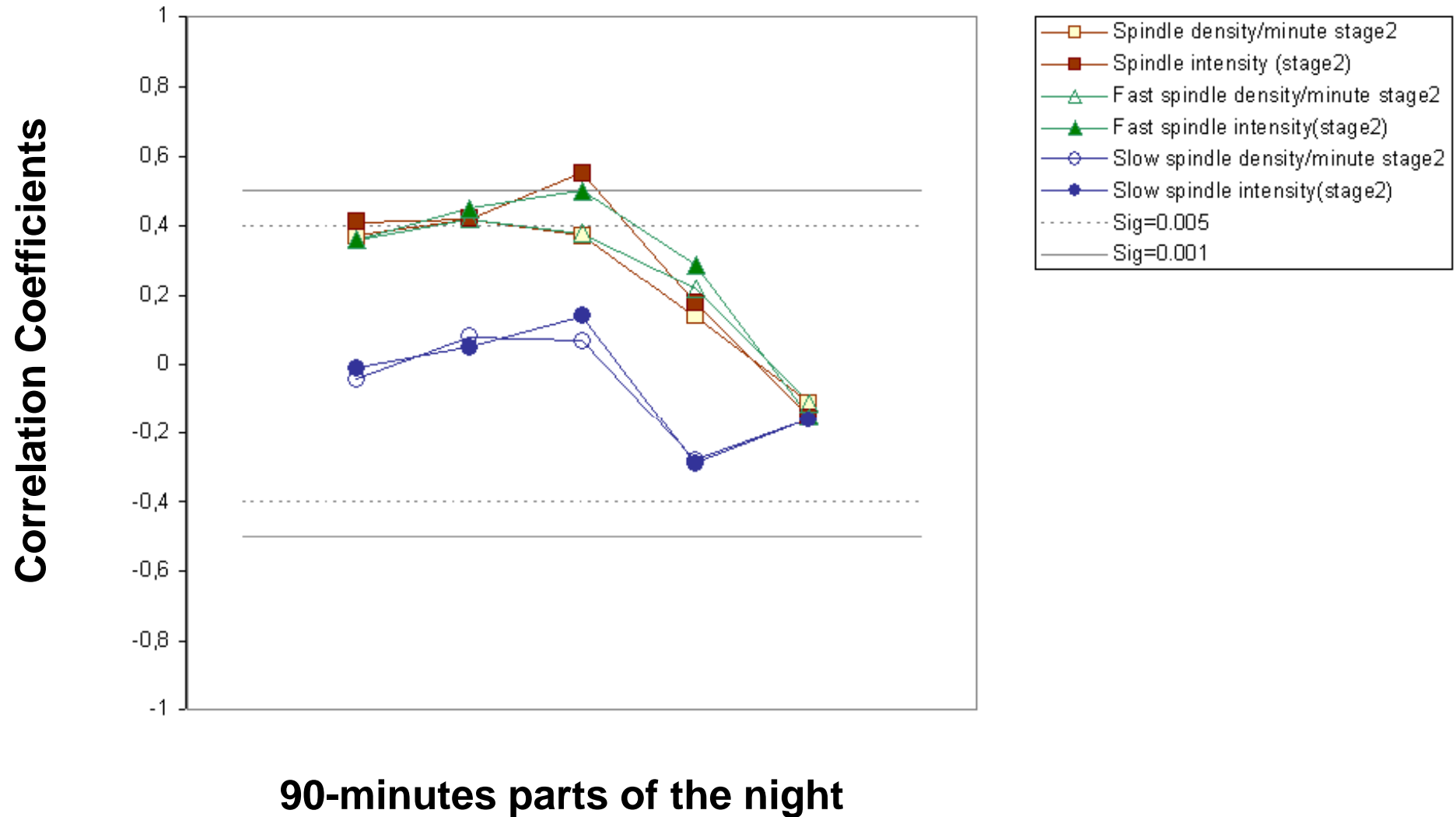
# Changes in slow (<13 Hz) intensity (learning – control night) vs. overnight changes in memory performance



Correlations

		CHANGE	SPIS_D
Pearson	CHANGE	1,000	-,060
Correlation	SPIS_D	-,060	1,000
Sig. (2-tailed)	CHANGE	,	,782
	SPIS_D	,782	,
N	CHANGE	24	24
	SPIS_D	24	24

# Correlation of spindle measures and overnight changes in memory performance during the course of the night



# Summary

- Changes in fast ( $> 13$  Hz) spindle activity during S2 sleep correlate significantly with changes in declarative memory performance before and after an experimental night.
- The observed correlations are highest in the early parts of the night.
- These results provide direct evidence for the involvement of sleep spindle activity in the consolidation of explicit memory.