Experimental Design, Data Analysis, and Applications for the Event-Related Potentials

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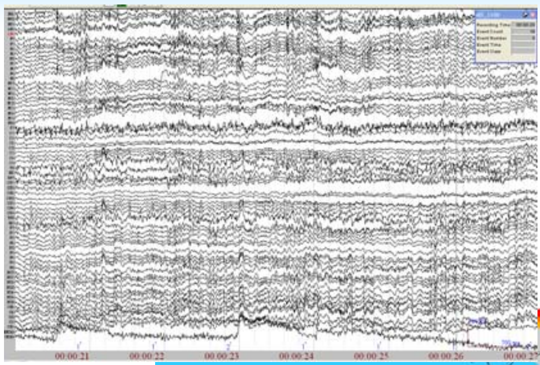
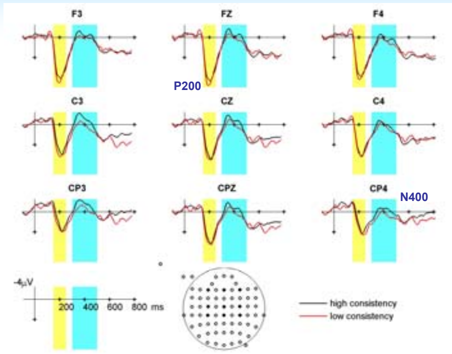
From EEG to ERP



An ERP study: the consistency effect in reading low frequency characters



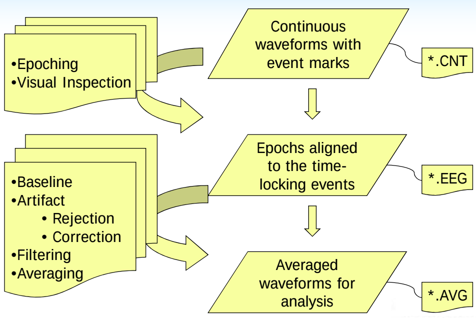
Frequency	Consistency: High	Consistency: Low
High	議	緒
Low	裱	冶

Lee et al., 2007

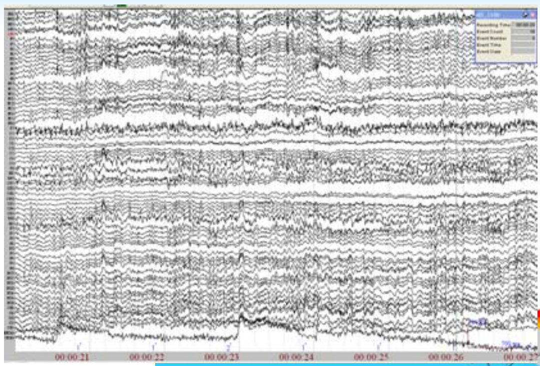
Outline

- Measuring ERPs
  - Steps for data processing
  - How to deal with artifacts
  - ERP amplitude and latency measurements
- The principle for Experimental design
- The limitation of ERPs
- Possible Applications

Outline

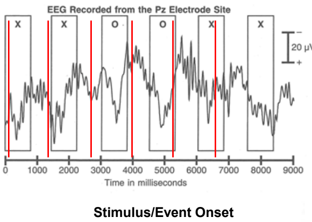


From EEG to ERP



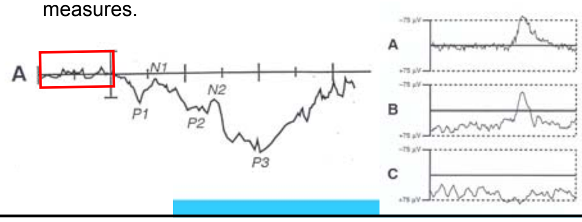
Epoching

- Extract the waves of a specified duration, which are synchronized with types of event, from the ongoing EEG.

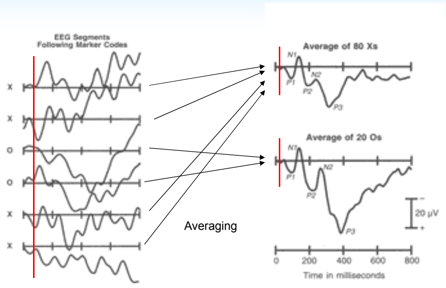


Baseline correction

- Baseline: Use pre-stimulus interval as baseline (100-200 ms before stimulus onset): assume the voltage in this period is unaffected by the stimulus.
- It is important to select an appropriate baseline, because any noise in the baseline will add noise to your measures.

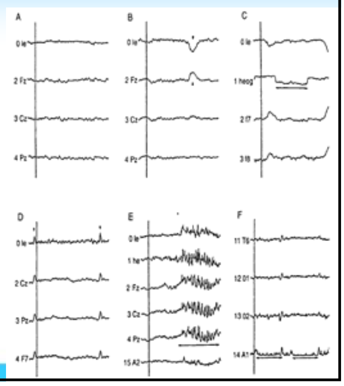


From Epoch to Grand Average



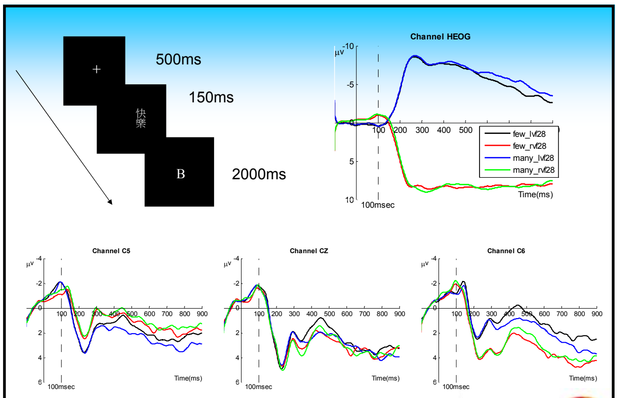
Types of artifacts

A. Clean EEG
B. Eye-blink
C. Lateral eye-movement
D. Heartbeat
E. Excessive muscle
F. Amplifier blocking



Problems with Artifact

- Artifacts can be problematic in two ways
  - Usually are very large compared to the ERP signals and may greatly decrease SNR of averaged ERP waveform.
    - EEG is on order of + 50 microvolts
    - ERPs (that we are interested in) are on order of 2 – 20 microvolts
    - Often want to detect differences of 1-2 microvolts
  - May be systematic occurring in some conditions (e.g., go/nogo) or time-locked to the stimulus(e.g., split visual field) so that they are not eliminated by the averaging process.



Two ways for eliminating artifacts

- Artifact rejection

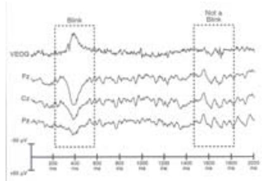
  to detect large artifacts in the single-trial EEG epochs and simply exclude contaminated trials from averaged ERP waveforms

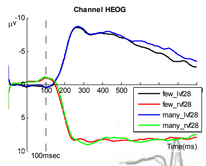
- Artifact correction (mathematical)

  use correction procedures to subtract away the estimated contribution of the artifacts

The general process of detecting the artifacts

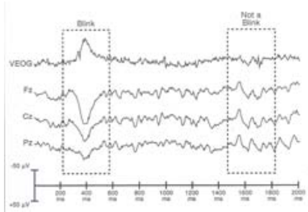
1. Choosing an artifact measure sensitive to the signal of the artifact.
2. Set the rejection criterion for the output value of the function





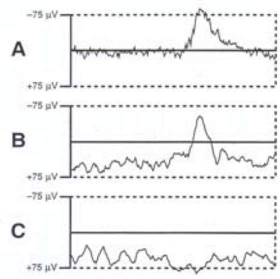
Blinks

- VEOG shows a deflection of 50-100 uV with a typical duration of 200-400ms.
- The waveform is opposite in polarity for sites above versus below the eye.



Blink

- Blink-EOG (+-75μV)
- The difference between minimum and maximum (peak-to-peak)
- or, run baseline correction in advance

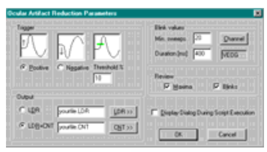


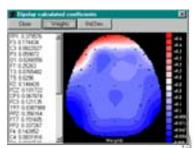
Artifact correction

- When do we need to correct rather than reject artifacts?
  - Limited trial numbers.
  - Some groups of participants (e.g., children and psychiatric pts) who cannot easily control their blinking and eye movement.
  - Task demand (e.g., sentence reading).

Some methods of correction

- Eye blinks and movements
  - Calculate the propagation factor between the eyes and each of the scalp and subtract a corresponding proportion of the EOG from the waveform at each scalp site.
  - ICA or source localization techniques



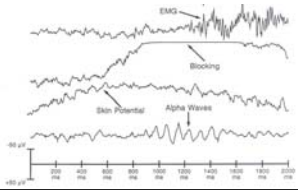


Problems with artifact correction

- Artifact correction may significantly distort the ERP waveforms.
- Require significant additional efforts.
- Can not account for the changes in sensory input caused by blinks and eye-movement (e.g., stimuli may not be seen properly due to blink/eye-movement).

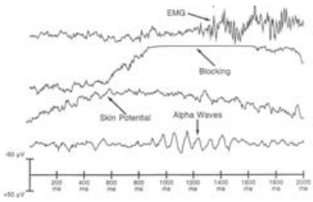
Other artifacts

- Muscle and heart activity
  - EMG can be eliminated by low-pass filter
  - EGK, ICA/PCA
- Amplifier saturation
  - Blocking: the EEG is flat for some period of time.
  - Change the gain on the amplifier.
  - X-within-Y-of peak
    X: number of points, Y: value close to peak
- Alpha waves
  - Use well-rested subject
  - Avoid a constant stimulus rate (Jitter +-50 ms in the intertrial interval)



Filtering – another way to reduce noise

- Most of the relevant portion of the ERP waveform in a typical cognitive neuroscience experiment consists of frequencies between 0.01Hz and 30Hz.
- EMG >100Hz
- Slow voltage shifts



Hansen's Axiom: there is no substitute for good data.

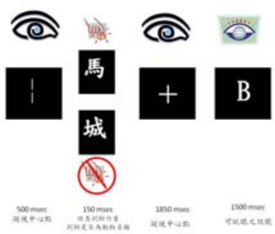
- It is always better to minimize the occurrence of artifacts rather than rely on rejection or correction procedures.

Reducing is better than rejecting

- Wear glasses instead of contact lens.
- Prepare eyedrops.
- Use short blocks of 1-2 mins to provide frequent rest breaks or to insert "mini-blocks" within the normal blocks.
- Instruct the participants to blink after making a response in each trial.

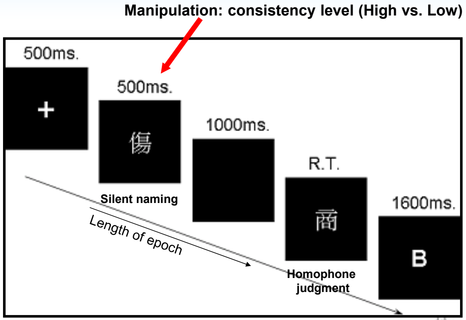
國小學童對構字規則的掌握

	真字	假字	非字	動物名
筆畫數	12.44 (±2.95)	12.02 (±2.58)	12.42 (±2.40)	12.22(±4.11)
	時	[illegible]	[illegible]	豬



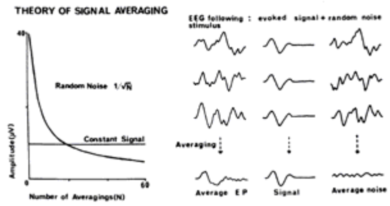
改變作業型態
ex: naming→ homophone judgment

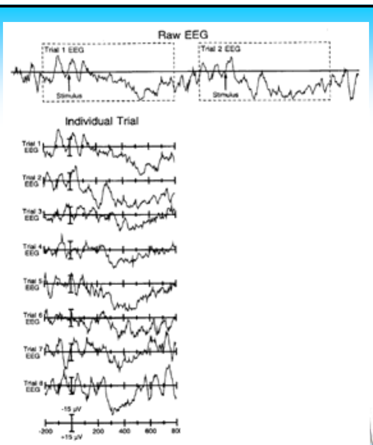
Manipulation: consistency level (High vs. Low)



The Averaging Process

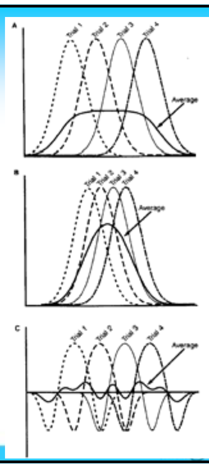
- Signal Averaging
  - The EEG data collected on a single trial is assumed to consist of an ERP waveform plus random noise.
  - The ERP waveform is assumed to be identical on each trial, whereas the noise is assumed to be completely unrelated to the time-locking event.



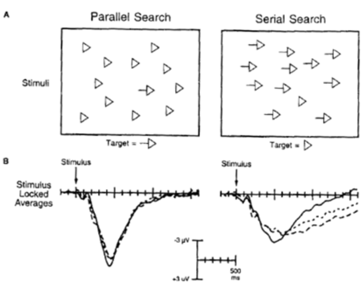


Latency Variability

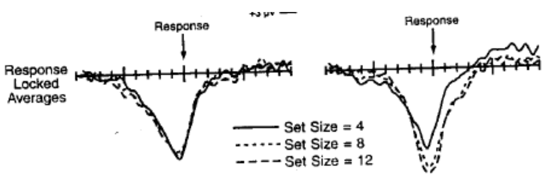
- It's particular problematic when amount of latency variability differ across conditions or groups.



Prediction: Increased P3 latency and amplitude at the larger set sizes in serial search, but not in the parallel search

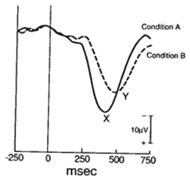


- Response-locked averages
  - Variations in the latency of an ERP component are correlated with changes in reaction time.



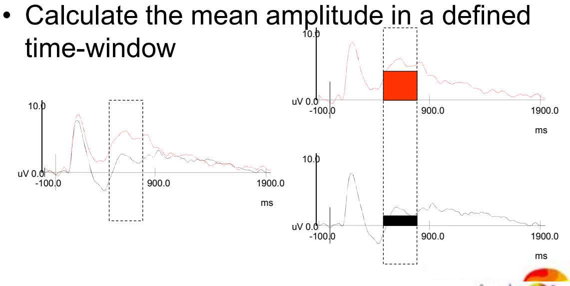
Measuring the components

- Measuring Amplitude
1. Peak amplitude
2. Mean amplitude
- Measuring Latency
1. Peak latency
2. Fractional area latency

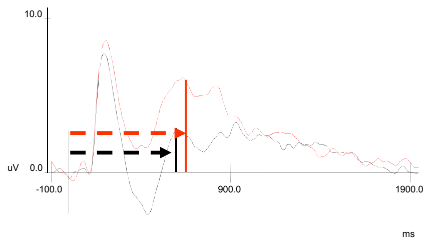


Waveform -- Mean Amplitude

- Calculate the mean amplitude in a defined time-window



Waveform – Peak Latency



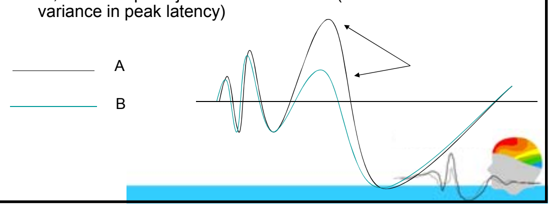
Interpreting ERPs

ERPs may be used to make inferences …

- About the brain
  - Time course of processing
  - Presence of a processing difference
  - Nature of that difference
  - Spatial location (must be cautious)
- About cognition
  - Requires a linking hypothesis, a statement that links a particular cognitive process or state to a particular type of change in a measure.

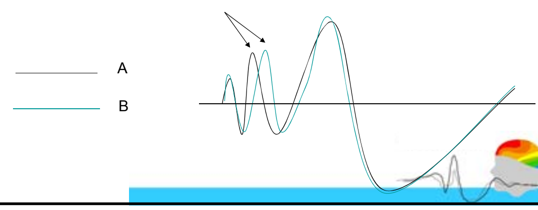
Amplitude difference

- Typical conclusion is of qualitatively similar neural processing that differs in degree
- Important to remember that we are looking at an average, so amplitude difference could be due to:
  - smaller/larger amplitude signal on most trials
  - or, more temporal jitter in one condition (need to examine variance in peak latency)



Latency difference

- Typical conclusion is that qualitatively similar neural processing takes place in the two cases, but with a different time course.
- May cause qualitatively different processing downstream



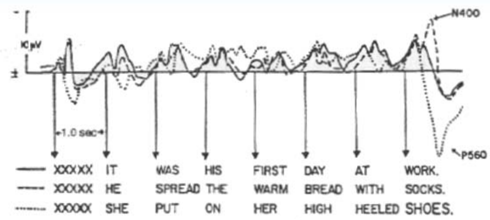
Two Strategies for using ERPs

- To identify the cognitive processes underlying the component
- Use a known ERP component to study some aspects of comprehension, even if the cognitive and neural events underlying the component have not been identified.

  This approach becomes feasible once the component is shown to systematically covary with manipulations of stimuli, tasks, or instructions that influence the cognitive process of interest.

  e.g., N400, P600

N400: Semantic Violation detector



The N400 was first described in an experiment contrasting semantically predictable with semantically incongruent sentence completions (Kutas & Hillyard, 1980).

Semantic constrain and cloze probability

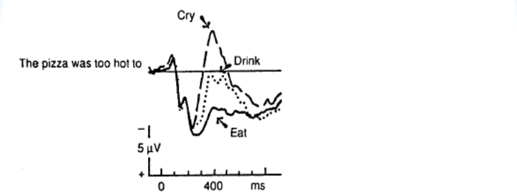
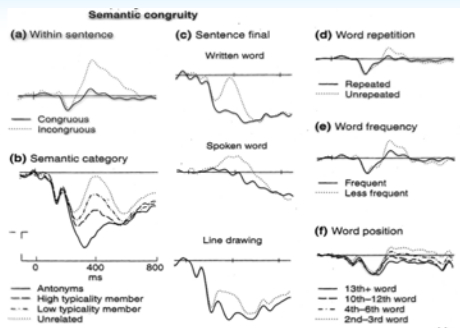


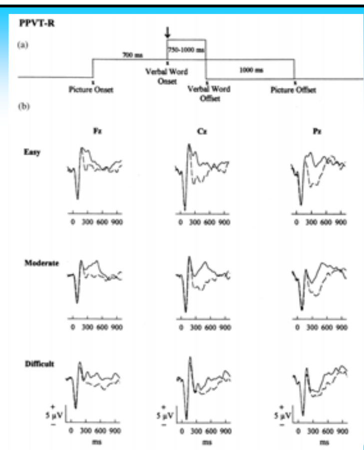
FIG. 4 ERPs elicited by sentence-final words at a midline central site, showing the positivity *(solid line)* for a predictable word. N400 elicited by an incongruous word *(dashed line)*. When the final word is semantically incongruent but related to the expected final word *(dotted line)*, it elicits a smaller N400 than an unrelated incongruity. Sample endings are for illustrative purposes only, since the same sentence frames were never repeated in this experiment. Figure from Kutas et al. (1984). Copyright Raven Press. Reprinted with permission.

The amplitude of N400 is inversely correlate to the degree of semantic congruency and cloze probability.

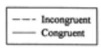
The N400



Applications for neuropsychological assessment

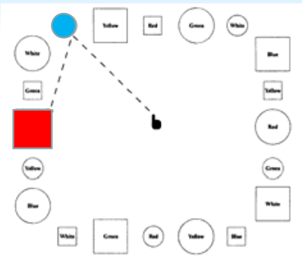


An application of N400 for the Peabody picture vocabulary test-Revised (PPVT):
A tool for evaluation of vocabulary knowledge



Connolly et al., 1995

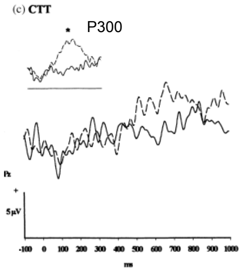
Computerized Token task(CTT): speech comprehension



correct sentence
Touch the small blue circle and the large red square

Incorrect sentence
Touch the small blue circle and the large green square

Case:LG, dyslexia, show normal speech comprehension



Psycholinguistic assessments of language processing (PALPA) for reading comprehension

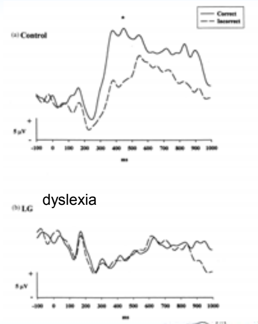
•An application of P300 of sentence comprehension task

•Picture-sentence matching task

•Study phase: Participants saw a set of three pictures and the accompanying sentence with the instruction to read the sentence and decide which picture is correct.

•Test phase: Present each of picture separately

•The P300 following correct, but not incorrect pictures, was interpreted to reflect a successful performance on the PALPA.



Auditory change detection paradigm:
P300 and Mismatch Nativity (MMN)

Oddball paradigm: pure tone

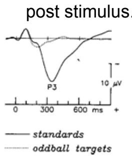
- Stimuli:
  - Standard ♪ : 1000Hz, 80% (of stimuli)
  - Deviant ♪ : 1200Hz, 20%
- Procedure:

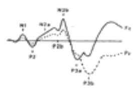
♪ ♪ ♪ ♪ ♪ ♪ ♪ ♪ ♪ ♪….

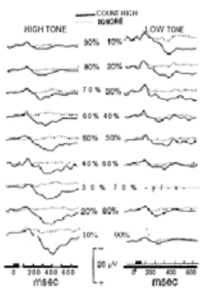
♪ = 100 ms, SOA = 800 ms

P300(P3, P3a, P3b)

- A positive waveform elicited by low probability deviant stimuli, broadly distributed across the scalp with a posterior maximum and a peak around 300 ms post stimulus.







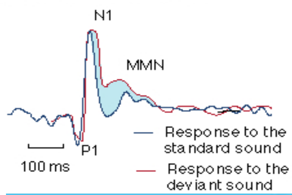
Mismatch Negativity (MMN)

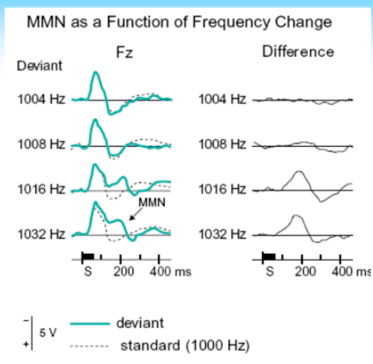
MMN is a component of the **auditory** ERPs, which is elicited by an infrequent change in a repetitive sound (**oddball task**).

♪ ♪ ♪ ♪ ♪ ♪ ♪ ♪ ♪ ♪….

Standard ♪ : 1000Hz, 80%
Deviant ♪ : 1200Hz, 20%

Brain's responses (event-related potentials) to standard and deviant sounds

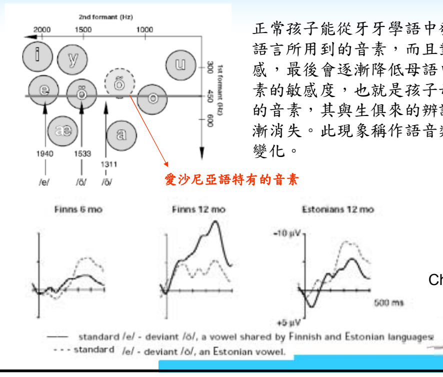




MMN: reasons for wide applicability

- *Inexpensiveness*
- *Easiness*
- *Attention-independent elicitation*
- The objective measure for
  - the accuracy of central auditory processing correlates with perceptual accuracy.
  - the permanent auditory memory traces (e.g. speech-sound memory traces).

嬰幼兒發展出特定使用語言的語音知覺能力

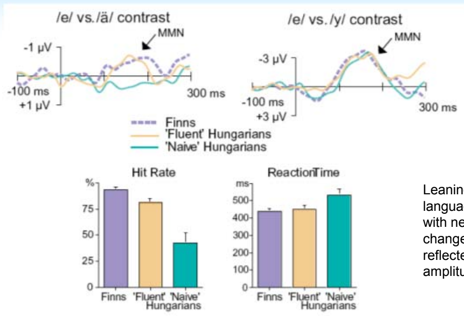


正常孩子能從牙牙學語中發現自己的語言所用到的音素，而且對其特別敏感，最後會逐漸降低母語中不存在音素的敏感度，也就是孩子母語中沒有的音素，其與生俱來的辨識能力會逐漸消失。此現象稱作語音類別知覺的變化。

愛沙尼亞語特有的音素

Cheour et al., 1998

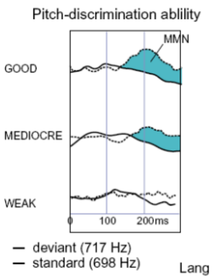
Neuronal plasticity in foreign language learning



Leaning a foreign language is associated with neural sensory changes which is reflected by the MMN amplitude.

Winkler et al., 1999

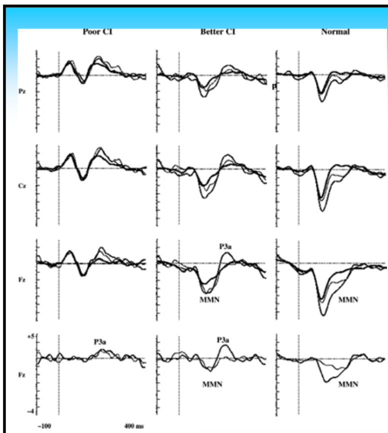
MMN as a function of behavioral pitch-discrimination accuracy



The MMN (recorded in a separate reading condition) was larger in amplitude in school children classified as “good” in a behavioral pitch-discrimination task (Seashore’s test of musicality) than those who were “mediocre” or “weak” in this task.

Importantly, the results of behavioral studies can be related to the results of MMN studies

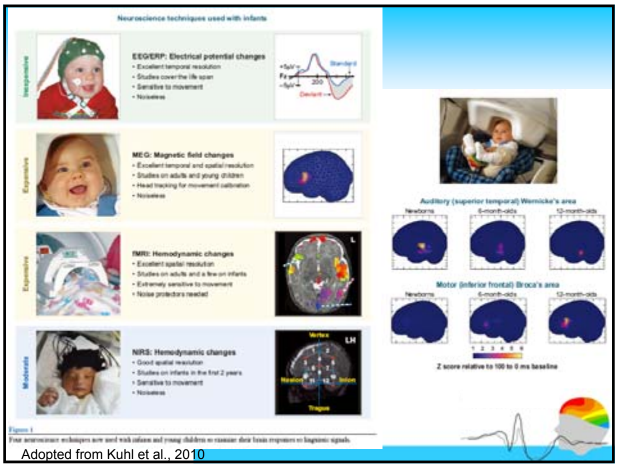
Lang et al.,1990



Standard：1000Hz
Small deviant：1250Hz
Large deviant：1250Hz

Result
CI (cochlear implant) **subjects with poorer speech scores had small or absent MMN to the smaller deviant stimulus.**

Kelly et al., 2005

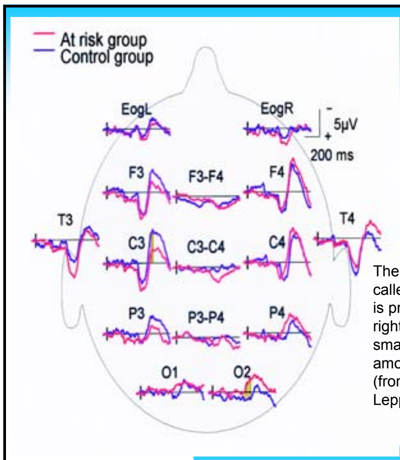


Adopted from Kuhl et al., 2010

ERP recording

From: F3, F4, C3, C4, P3, P4 (Ag/AgCl-electrodes), referred to ipsilateral mastoid

Bandpass: 0.5-35 Hz, sampling rate 200 Hz



The deflection of negative polarity called mismatch negativity (MMN) is present in both groups in the right hemisphere but is clearly smaller in the left hemisphere among at- risk children (from Leppänen & Lyytinen, 1997; Leppänen et al. 2002).

用新生兒時所量得之大腦語音區辨反應，可以預測兩歲半和五歲時的語言能力

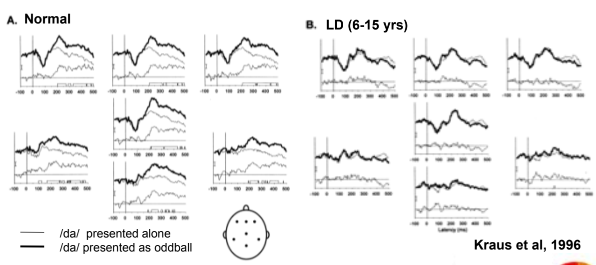
TABLE II

Correlations between Mean Amplitude of the Responses to /ga/ at 540-630 msec and Later Language and Verbal Memory Measures

	Left hemisphere			Right hemisphere	
Measure:	N	r	p	r	p
Receptive language 2.5 years	40	– .289	.035	– .426	.003*
Expressive language 2.5 years	43	– .215	.083	– .104	.253
Receptive language 3.5 years	43	– .291	.029	– .189	.112
Expressive language 3.5 years	43	– .314ᵃ	.020	– .198ᵃ	.101
Receptive language 5 years	42	– .374	.007	– .395	.005
Expressive language 5 years	44	– .272	.037	– .267	.040
Verbal memory 3.5 years	43	– .321	.018	– .048	.380
Verbal memory 5 years	43	– .474	.001*	– .308	.022

*p < .004 (.05/16, 1-tailed). ᵃ Spearman's correlation coefficient.

MMN 與學習障礙



學習障礙的孩子對於語音的變比較有問題，大腦沒有明顯的MMN 反應

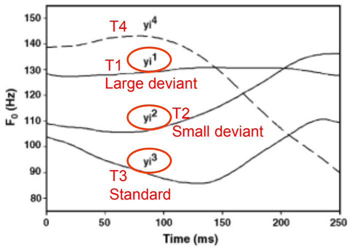
嬰幼兒聲調與音素覺知與閱讀發展的關係

Brain and Language Laboratory

Institute of Linguistics, Academia Sinica

國語聲調變化

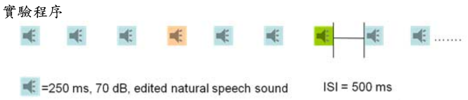
- 國語是聲調語言，用四個聲調來區辨意義
- 四個聲調中，二聲與三聲的相似性高於一聲與三聲的相似性



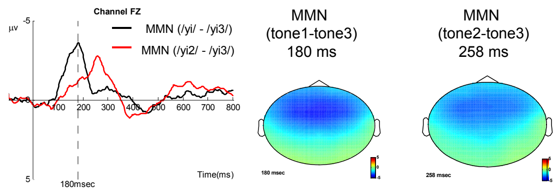
Multi-deviants oddball paradigm

	標準刺激(80%)	小差異刺激(10%)	大差異刺激(10%)
聲調	*Yi3* [i] (T3)	*Yi2* [i] (T2)	*Yi1* [i] (T1)
音首	*ba* [pa]	*da* [ta]	*ga* [ka]
韻尾	*da* [ta]	*di* [ti]	*du* [tu]

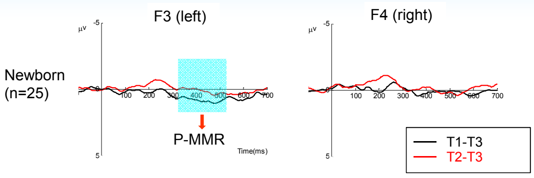
實驗程序



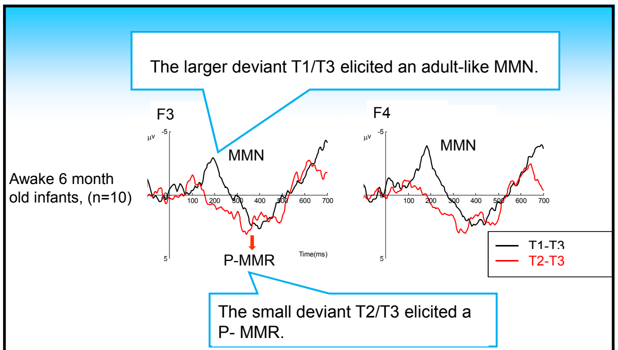
成人資料



新生兒

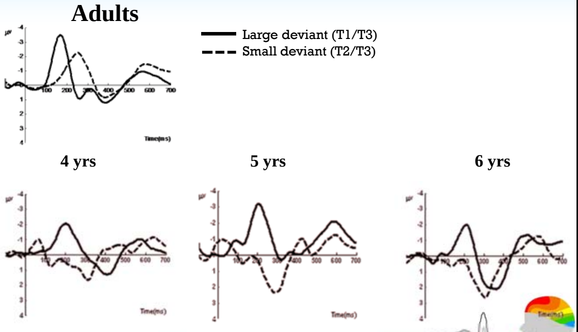


The large deviant T1/T3 elicited a significant P-MMR in sleeping newborns



The transition from P-MMR to MMR seems not only to be affected by maturation, but also by the size of deviance.

From P-MMR to MMN



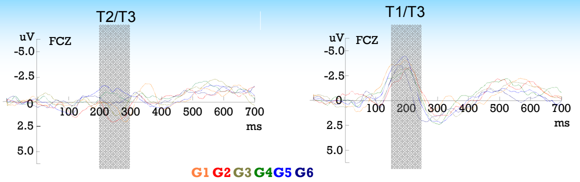
四歲時所測得之MMRs 與一年級的閱讀表現具相關

A test batteries of phonological awareness (PA), rapid naming test (RAN), Chinese character recognition test (CCRT), and a subset of Primary Scale of Intelligence-Revised, WPPSI-R, measured at 7 years old (G1, N=15).

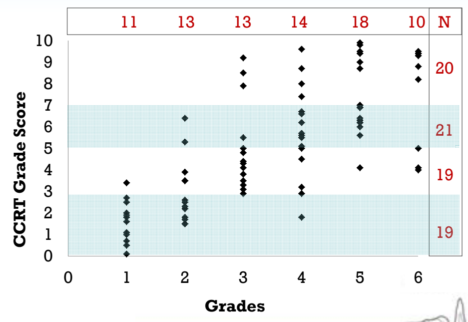
	Large deviant (T1-T3)		Small Deviant (T2-T3)	
	150-200 msec		150-200 msec	
Reading related tests	r	P value	R	P value
Zhu-Yin-Fu-Hao recognition	-.67	0.005		
PA -- deletion task	-.66	0.007	-.53	0.043
RAN	.51	0.050		

Larger MMN measured at 4yrs predicts better ZhuYin and PA score, and faster RAN speech at G1.

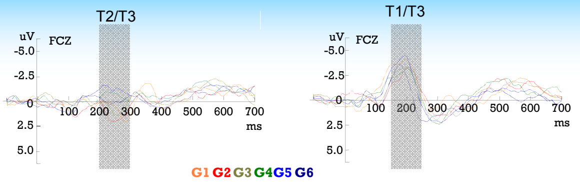
國小學童　根據年級分組



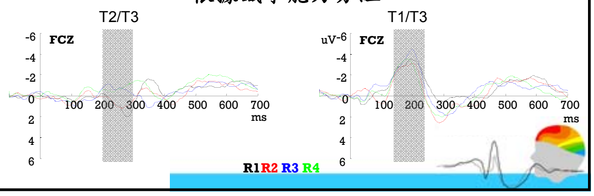
識字量與年級如何影響的MMN變化



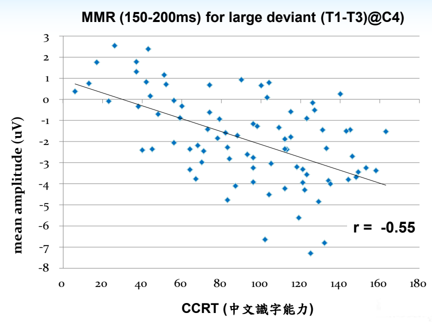
根據年級分組



根據識字能力分組

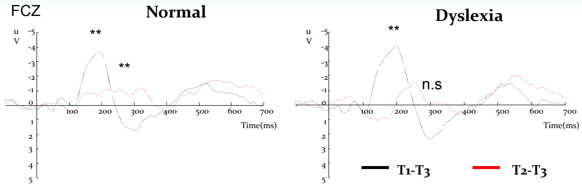


中文聲調MMR 與閱讀能力的相關



以MMN評估閱讀困難與一般學童的語音區辨能力

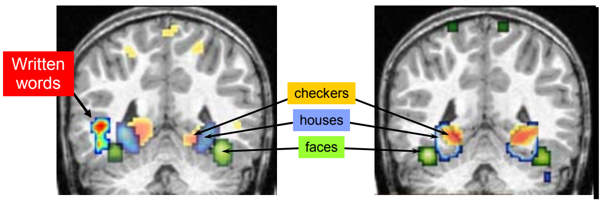
MMRs to lexical tones in normal and dyslexic readers



	MMN	
	Small Diff T2–T3	Large Diff T1–T3
Normal	150-250msec	100-250msec
Dyslexia	n.s	150-250msec

An fMRI study of normal and impaired reading

The ventral mosaic in normal 9-year-old readers … and in impaired readers



The VWFA activation correlates tightly with reading scores (replicating Shaywitz, Pugh et al.)

Deheane et al., 2011

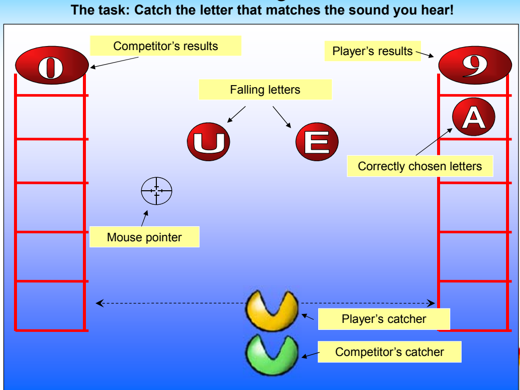
When & how does the sensitivity of brain to print emerges?

- Reading in alphabetic languages: grapheme-phoneme correspondence
  →additional function adopted by visual-processing units
  →sensitized to print processing through practices
- -32 nonreading kindergarten children
- -Behavioral + fMRI + ERP

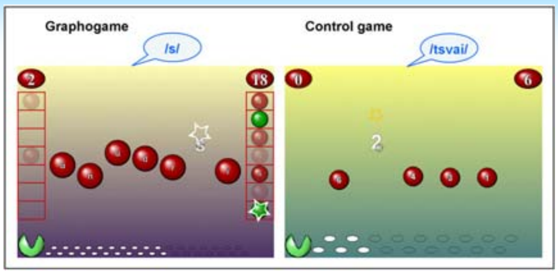
Brem et. al., 2010

Literate game

The task: Catch the letter that matches the sound you hear!

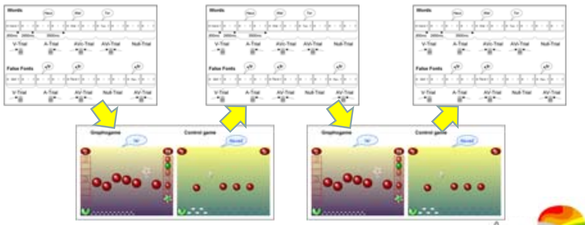


Programming: Tuomo Hokkanen



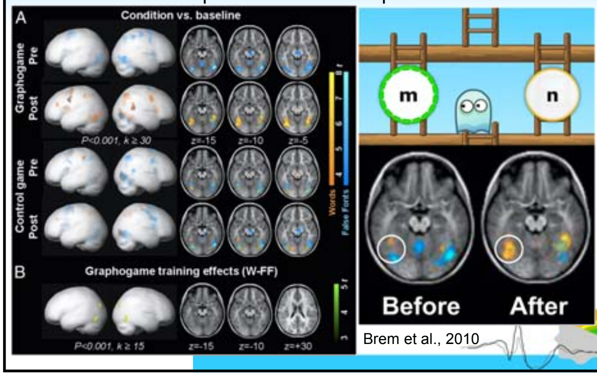
Experimental design

T1	GG	T2	NC	T3
	NC		GG	



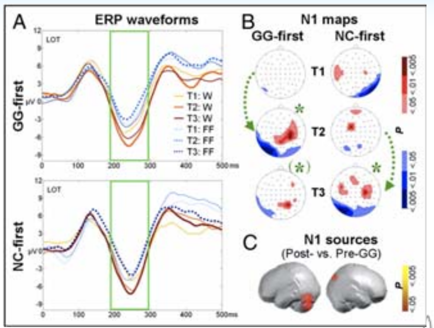
Educational Neuroscience

Brain sensitivity to print emerges when children learn letter–speech sound correspondences

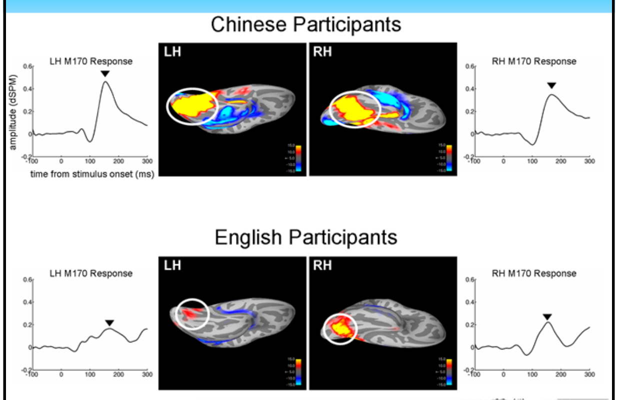


Brem et al., 2010

Training effect on N170



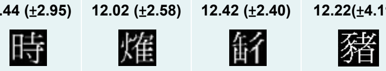
中文的構字知識

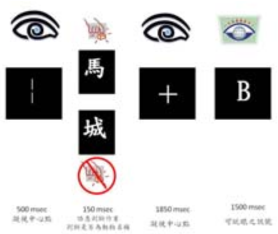


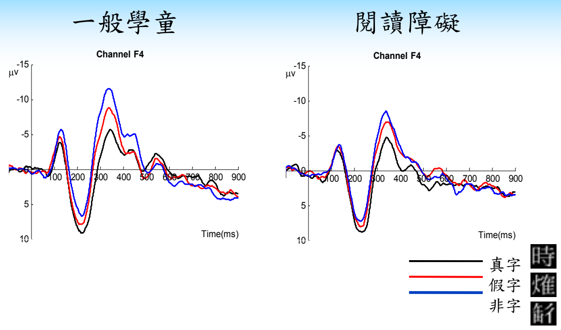
Hsu, Marantz, Lee, 2011

國小學童對構字規則的掌握

	真字	假字	非字	動物名
筆畫數	12.44 (±2.95)	12.02 (±2.58)	12.42 (±2.40)	12.22(±4.11)







The goal of experimental design

- Collect stable, within-subject ERPs
- Plan ahead for effects of interest
  - avoid confounds
  - have strategies for dealing with confounds/issues that cannot be avoided

When control is not possible, look at the effects of the potentially confounding variable directly

Design Tips

To collect clean ERPs, you need …

- Enough participants (usually 18-30 for language study)
  - age, handedness, language history all matter
- Enough trials per condition
  - for a big effect: 25-60
  - for a medium effect: 100-200
  - for a small effect: 400-800
- Low artifact rejection rates (< 15%)
- For auditory ERPs, good time-locking

When in doubt, collect more data!

Design Tips

To collect interpretable ERPs, you should …

- Focus on a specific component (or two)
  - Ideally, components that do not overlap
  - Bigger components are easier to work with
- Or, ask questions that do not rely on the identification of components
- Use well-studied experimental manipulations

Conclusions

- These cognitive processes are reflected in different electrophysiological responses with different time-courses, mediated by different brain areas.
- With the right design, careful measurement, and circumspect inferences, therefore, ERPs can be used to learn the underlying mechanism of the neuro-cognitive function.
- Interdisciplinary collaborations!

Foundations for a New Science of Learning

Adopted from Meltzoff et al., 2009

致謝

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  - 福德國小
- 桃園縣
  - 大勇國小
  - 大崙國小
- 高雄縣
  - 誠正國小
  - 長樂國小
- 台北縣
  - 武林國小
  - 文林國小
  - 丹鳳國小
  - 江翠國小
  - 永福國小
  - 網溪國小
  - 大觀國小
  - 成州國小
  - 建國國小
  - 介壽國小
  - 錦和國小
  - 光復國小
  - 義學國小
  - 中山國小
  - 坪林國小
  - 屯山國小
  - 民安國小
  - 樹林國小
  - 正義國小
  - 樟樹國小
  - 舊莊國小

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