114年中樞聽覺處理異常研習

認識中樞聽覺處理系統及異常

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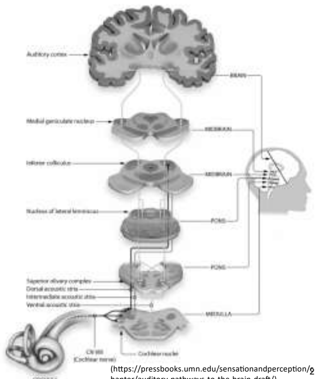
大綱

- 認識中樞聽覺處理系統➔我們如何聽懂聲音
  - 中樞聽覺神經系統 (central auditory nervous system, CANS)
- 認識中樞聽覺處理異常 (central auditory processing, CAPD)

我們如何聽懂聲音

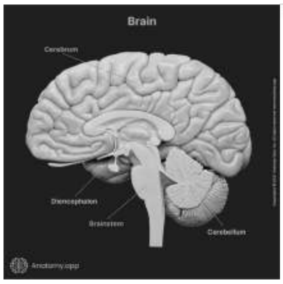
- 聽覺系統
  - 周邊聽覺系統：外耳、中耳、內耳、聽神經
  - 中樞聽覺系統 (CANS)
- 聽覺大腦

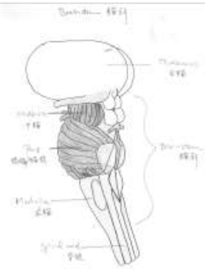


(https://pressbooks.umn.edu/sensationandperception/chapter/auditory-pathways-to-the-brain-draft/)

中樞聽覺系統

- 腦幹
- 大腦 (聽覺皮質)
- 胼胝體

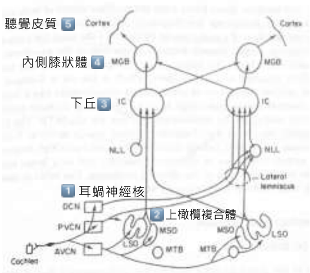




(anatomy.app)

中樞聽覺系統的運作特色

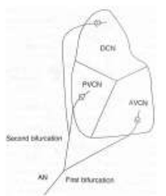
- 同側與對側
- 聚合與分散
- 興奮與抑制
- 上行與下行
- 典型與非典型
- 音調排列組織
- 神經同步性

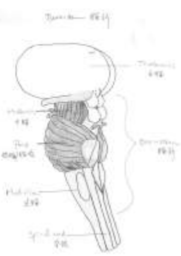


(Pickles, 2003)

耳蝸神經核(Cochlear nucleus, CN)

- 位在小腦橋腦角(cerebellopontine angle, CPA，延腦與橋腦交界處)
- 有三個主要的神經核團
  - 前腹耳蝸神經核(AVCN)-、後腹耳蝸神經核(PVCN)、背側耳蝸神經核(DCN)
- 聽神經分枝分佈於每一個核團

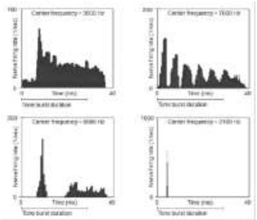




(Møller, 2012)

耳蝸神經核(Cochlear nucleus, CN)

➢有不同放電型態的神經元：可加強聲音特徵



(Auditory function: Physiology and function of the hearing system - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/12-PST-histograms-illustrating-different-types-of-neuron-firing-patterns-observed-in_fig7_301532255 [accessed 31 Aug, 2023])

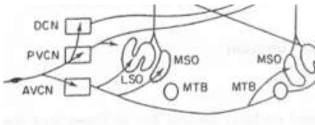
上橄欖複合體(Superior olivary complex, SOC)

➢位於腦幹的橋腦 (pons)，是接收雙耳訊息的第一站

➢內側上橄欖核 (MSO)：接收來自兩側耳蝸神經核的訊號

➢斜方體 (MTB)：接收來自對側耳蝸神經核的訊號，再傳至同側外側上橄欖核

➢外側上橄欖核 (LSO)：接收來自同側耳蝸神經核的訊號，還有同側斜方體轉傳的訊號

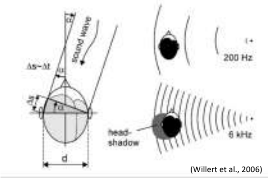


(Pickles, 2003)

上橄欖複合體(Superior olivary complex, SOC)

➢雙耳訊號處理：聲源辨識、噪音背景聆聽

- 接收來自兩側耳蝸神經核的訊號：分散與聚合
- 某些細胞偏好特定時間差異
- 對側路徑的抑制作用強化雙耳之間的訊號差異



(Willert et al., 2006)

下丘(Inferior colliculus, IC)

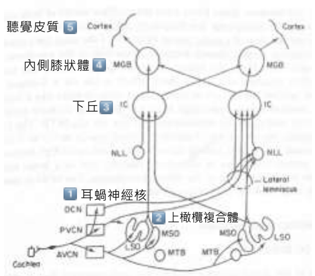
➢位於腦幹的中腦

➢兩側下丘由連合纖維連接(下丘臂)

- 雙耳訊號處理
- 振幅調變處理

➢部份核團屬非主要上行路徑

- 聽覺反射中心



丘腦(Thalamus)

➢腦幹與皮質之間的資訊交通站

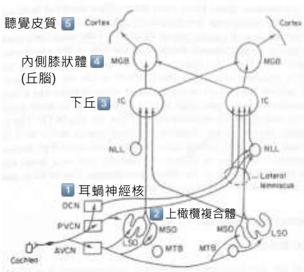
- 嗅覺除外
- 注意力與選擇性聆聽

➢內側膝狀體(MGB)在多感官整合扮演重要角色(也參與非主要上行路徑)

➢相位鎖定差 (<200Hz)➔基頻/音調、振幅調變

➢母音、時間線索變化少的子音編碼應已完成

➢部份細胞對雙側訊息及單側訊息的反應不同➔雙耳訊號處理



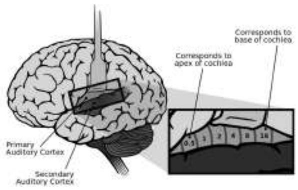
初級聽覺皮質區

➢赫氏迴(Heschl's gyrus)、A1

➢接收自丘腦的內側膝狀體(MGB)的訊息

➢有音調排列組織

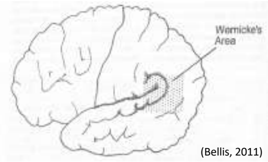
➢雙耳訊息、音量、音節訊息、利用位置理論處理更快速時間訊息，例如塞音辨識



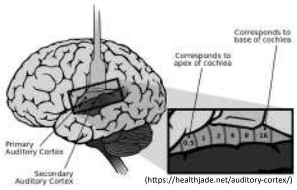
(https://healthjade.net/auditory-cortex/)

聽覺聯合皮質區

- ➢Wernicke’s area
- ➢辨識語音、理解口語，以建立語言能力
- ➢由於延伸至下頂葉，可能與閱讀和寫作有關
- ➢多感官與多功能整合

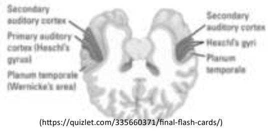


(Bellis, 2011)



(https://healthjade.net/auditory-cortex/)

大腦聽覺區的不對稱

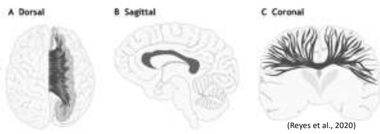


(https://quizlet.com/335660371/final-flash-cards/)

- ➢左側聽覺皮質區較大
- ➢多數人的語言功能優勢在左腦(分析式語法、語意處理、音韻分析、辨識、詞彙提取等)
  - 非絕對
  - 大部分的左撇子呈現典型的左半腦語言優勢，但有15%的左撇子呈現相反或對稱的半腦優勢
- ➢右腦：負責節奏、重音、聲音輪廓、非語音聲音事件等
- ➢功能側化在丘腦層次也有

胼胝體

- ➢最大的連合纖維(白質帶)
- ➢聽覺處理在後半部份
- ➢功能：雙耳訊號處理、聲源辨識、用語言命名非語言的聲音訊號、說出雙耳異訊左耳訊息



(Reyes et al., 2020)

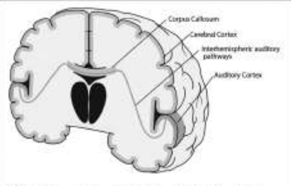
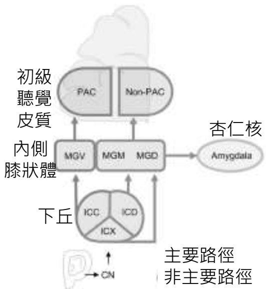


FIGURE 1 | Coronal schematic illustration of the interhemispheric auditory pathways connecting right and left auditory cortices. Corpus Callosum (blue), interhemispheric auditory pathways connecting right and left auditory cortices (red).

(Steinmann et al., 2014)

非主要上行路徑

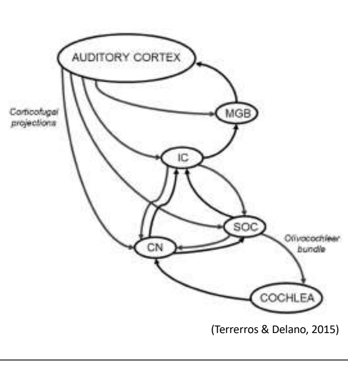
- ➢不具音調排列組織
- ➢有其他感官訊息參與， 如體感、視覺，因此對聲音和其他刺激會產生反應，如觸摸和光線
- ➢與邊緣系統連結
  - 下路徑(low route)



(Brinkmann et al. 2021)

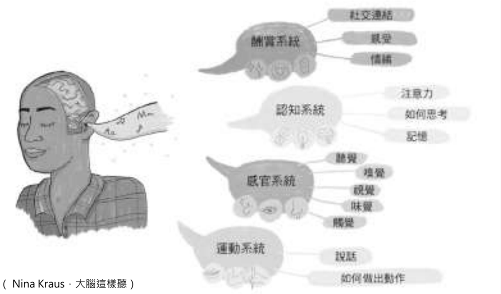
下行路徑(傳出)

- ●三個迴路
- ●影響延伸至耳蝸
- ●影響聲音的處理



(Terreros & Delano, 2015)

聽覺大腦：我們如何聽懂聲音



（ Nina Kraus，大腦這樣聽 ）

中樞聽覺系統CANS的發展

- ➢Human auditory maturation can be studied at three levels: the structural, the functional, and the behavioral.
- ➢成熟化(髓鞘化&樹突分枝)與老化影響中樞聽覺系統的結構變化，伴隨著功能的改變
  - 刺激經驗
  - 樹突分枝與新突觸的發展終身持續
- ➢成熟進程：周邊➔中樞、尾端➔頭端

Age	Structural	Electrophysiological	Behavioral
<6 mos I	Layer I cortical axons are mature Acoustic radiation myelination starts	ABR wave I latency mature ABR waves III-V, MLR, P2 and MMR present but latencies are immature	Discrimination of (speech) sounds, detection of change
6 mos–5 yrs IV–VI	Brainstem axons are mature Acoustic radiation myelination mature Axonal neurofilaments in cortical layers IV, V and VI mature Cortical synaptic density peaks	ABR, MLR, P2, N2, MMN, and T-complex are mature P1 present but latency immature	Onset and development of perceptual language and general auditory perception
5–12 yrs II–III	Axonal neurofilaments in cortical layers II and III are mature Decrease in cortical synaptic density	P1 matures, N1 emerges but amplitude remains immature	Processing of masked and degraded speech improves
>12 yrs	Cortical axons are all mature Temporofrontal language-related nerve tracts mature	Asymptotic maturation of N1	Speech understanding in reverberation and background noise matures

(Musiek & Chermak, 2014)

CANS的發展

- ➢Corpus callosum 胼胝體
  - 厚度趨近成人：：約9歲
  - 半腦不對稱表現 vs. 年齡
- ➢分齡常模

Structure	Test	Maturity	Authors
Auditory nerve	ABR wave I	3–6 mo	Eggermont et al. (1991)
Brainstem	ABR–click	2 yr	Eggermont (1988)
Brainstem	ABR–mid freq	2 yr	Ponton et al. (1992)
Thalamus	DTI	20 yr	Mukherjee et al. (2001)
Thalamus	DTI	15–20 yr	Lebel et al. (2008)
Acoustic radiation	histology	4–5 yr	Kinney et al. (1988)
Corpus Callosum	DTI	2 yr	Ding et al. (2008)
Auditory Cortex	MRI	12–16 yr	Su et al. (2008)
Temporal cortex	DTI	7–8 yr	Pujol et al. (2006)
SLF	DTI		Zhang et al. (2007)
SLF	DTI	13–20 yr	Lebel et al. (2008)
T complex, P2, Pa, Pb	AEP	1.5–2 yr	Eggermont (1988)
N2	AEP	5 yr	Ponton et al. (2000)
P1, N1, TP200	AEP	15–20 yr	Ponton et al. (2002)

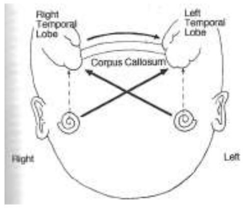
(Musiek & Chermak, 2014)

CAPD的開始

- ➢1950年代
  - Myklebust, H. R. (1954). *Auditory disorders in children: a manual for differential diagnosis.* Grune & Stratton.
    - ◆強調需要為溝通障礙的兒童評估中樞聽覺功能
    - ◆"that presented as a hearing loss but was found to exist in children with normal hearing, presenting as the inability to structure the auditory world and select those sounds which are immediately pertinent to adjustment"
  - Bocca, Calearo, & Cassarini (1954)
    - ◆評估顳葉損傷者的皮質聽覺：low-pass filtered speech
  - Braodbent (1954)
    - ◆第一個以雙耳數字測驗探討注意力與記憶力功能的學者

CAPD的開始

- ➢Kimura (1961)
  - 採用Broadbent的雙耳異訊測驗模式探討半腦不對稱與單側病灶對聽覺功能的影響
  - 發展出雙耳異訊的生理機制基礎
    - ◆對側傳導 > 同側傳導
    - ◆右耳得分 > 左耳得分 ➔右耳優勢
    - ◆間接證明左大腦的語音接收優勢



(Bellis, 2011)

CAPD的發展

- ➢對聽覺系統以及大腦運作的持續了解
- ➢測驗、篩檢工具的發展
  - 行為、電生理、造影等
- ➢1970晚期：在美國第一次舉辦全國性相關研討會
- ➢1990s起，專業學會/協會/研究團體陸續提出立場聲明、技術報告、臨床實務指引等文件
  - ASHA (1992, 1996, 2005b)、Bruton Conference paper (Jerger & Musiek, 2000)、AAA (2010)、BSA (2011, 2018)、NAL (2015)、Germany、Canada、The Netherlands…
- ➢ICD-10-CM：H93.25 (since 2015)

CAPD相關名稱

- ➢Auditory language disorder、auditory perceptual disorder、auditory perceptual problems、aphasic deaf、central deafness、auditory perceptually handicapped、central processing dysfunction、APD、CAPD、(C)APD
- ➢CAPD, e.g., ASHA (1996)
- ➢CAP, e.g., Jerger & Musiek (2000) Bruton consensus conference
- ➢(C)APD., e.g. ASHA (2005)

CAPD的定義與範圍

➢尚未有定論
- APD is characterised by poor perception of speech and non-speech sounds. It has its origins in impaired neural function, which may include both the afferent and efferent pathways of the central auditory nervous system (CANS), as well as other neural processing systems that provide 'top down' modulation of the CANS….APD is often found alongside and may contribute to primary disorders of those systems. APD may thus include both auditory and cognitive elements.(BSA, 2018)
- ….. they are considered higher order cognitive-communicative and/or language-related functions and, thus, are not included in the definition of (C)AP (ASHA, 2005)

CAPD的定義與範圍

➢Networks are nonmodular, temporally coupled, interfacing, polymodal or multisensory, overlapping, interconnected, and synchronized.

➢A review of the published literature reveals that attention can modulate auditory processing; however, the literature also confirms that auditory processing is not completely dependent on attention. (Musiek, 2016)

(Nina Kraus，大腦這樣聽)

CAP包含的聽覺能力或技巧 (ASHA, 2005)

➢聲音的定位與側化
➢聽覺辨識
➢聽覺型態辨識
➢聽覺的時間面向
➢競訊下的聽覺表現
➢降階訊息的聽覺表現

CAPD的本質 (ASHA, 2005)

➢(C)APD is best viewed as a deficit in the neural processing of auditory stimuli that may coexist with, but *is not the result of*, dysfunction in other modalities. At the same time, the noncompartmentalized brain, with its convergent sensory "tracks," multisensory neurons, and neural interfacing complicates a simple sorting out of causation versus coexistence. Thus, although many children with cognitive or language disorders may have difficulty processing spoken language, we should not automatically assume that a (C)APD is the underlying cause of their difficulties without the demonstration of an auditory deficit through appropriate auditory diagnostic measures.

共病 (comorbidity)

➢以Maggio & Geffner (2003)研究為例，425名7~14歲CAPD學生中
- 31%確診ADHD、53%疑似ADHD
- 83%有口語及語言問題
- 47%有閱讀障礙、27%完全沒有閱讀問題。有閱讀問題的男女比例為2:1
- 特殊懷孕、生產史(神經生理)：妊娠糖尿病、孕期抽菸、臍帶繞頸、產程缺氧、母親創傷、急產等
- 50%有中耳積水案史(maybe more due to asymptomatic condition)

➢共病不罕見

CAPD成因 (Etiological bases)

➢Acquired causes of CAPD in adults
- Neurological lesions or compromise of the CANS
  - ◆Neoplasma腫瘤
  - ◆Neurodegenerative processes (e.g., MS, Alzheimer's)
  - ◆Head trauma
  - ◆Impaired cerebral circulation (e.g., strokes)
  - ◆Aging, including central aspects of presbycusis
  - ◆Noise exposure
  - ◆Exposure to neurotoxic chemicals or heavy metals (e.g., styrene苯乙烯, lead, mercury)
  - ◆Epilepsy

CAPD成因 (Etiological bases)

- Etiology of CAPD in children➔neurobiological source of CAPD
  - Neurological lesions or compromise of the CANS 神經病灶或損傷
    - May include seizure disorder (e.g., Landau Kleffner syndrome), traumatic brain injury, neoplasms, neurodegenerative disorders, neurotoxicity, cerebrovascular accidents, metabolic disorders, and genetic disorders
  - Neuromaturational lag 神經發育延遲
    - Secondary to auditory deprivation and/or delayed myelin maturation in the subcortex, cortex and/or corpus callosum
  - Neuroanatomical abnormalities 構造異常
    - 通常為先天Congenital, and includes ectopic areas異位 and polymicrogyria多小腦回畸形 of the cortex, and other anatomical variances, e.g., CC, planum temporal顳平面
    - Children with dyslexia or learning problems

CAPD vs. 中耳積水

- For 6 decades, research has clearly shown that OME can have a lasting auditory effect, especially if it begins at a very early stage.
  - Greater adverse effect in the high frequencies
  - Articulation, language, auditory processing
  - Early effect of OME continued to influence reading ability and verbal IQ through the high school years.
  - ABR findings suggest that the early influence of early recurrent OM slows down auditory transmission at the brainstem level.

CAPD vs. 中耳積水

- 聽覺系統功能缺失vs.暫時性傳導型聽損
- 反覆性中耳炎vs.中樞聽覺系統缺失：自1960年代，即有研究結果提出
- 即時聽力回復，聽覺系統功能仍可能持續有缺失(直到青少年時期)

Relating OM to Amblyaudia　Relating ASQ to Amblyaudia (Whitton & Polley, 2011)

步驟

- 轉介Referral
  - The reason for the referral should be reviewed, considering whether further assessment will add anything to a diagnosis and/or support already in place
- 篩檢Screening
  - Case history
  - Questionnaire
  - Screening tools
  - Previous professional report
    - Including audiological testing
- 評估Diagnosis
- 擬訂介入管理計劃Developing a management plan

轉介：CAPD常見行為 (AAA, 2010)

- 在噪音或混響環境中難以理解口語
- 辨識聲源有問題
- 聽電話有困難
- 回答別人詢問時，回覆不一致或不適當
- 理解語速快的口語有困難
- 頻繁要求說話者重述以及/或是換句話說
- 遵從指令有困難
- 難以或無法察覺韻律中隱含幽默和諷刺語氣的細微變化
- 難以學習外語或新的口語語料，尤其是技術語言（行話）
- 維持注意力有困難
- 可能容易分心
- 歌唱、音樂能力，以及/或是音樂鑒賞力差
- 有學業困難，包括閱讀、拼寫以及/或是學習問題

案史Case History

- At minimum, should include
  - Auditory and/or communication difficulties experienced by the individual
  - Family history of hearing loss and/or central auditory processing deficits
  - Medical history, including birth, otologic and neurologic history, general health history, and medications
  - Speech and language development and behaviors
  - Educational history and/or work history
  - Existence of any known comorbid conditions, including cognitive, intellectual, and/or medical disorders
  - Social development
  - Linguistic and cultural background
  - Prior and/or current therapy for any cognitive, linguistic, or sensory disorder or disability

CAPD評估：綜合測驗模式

- CANS具高度冗贅性與複雜性
- 評估目的在於找出聽覺處理異常並針對缺失/優弱勢擬定管理計劃，所以需要進行完整評估
- 病灶或功能異常位置的區別診斷
  - 必要時進行醫療轉介

CAPD測驗類型 (ASHA, 2005)

- 聽覺辨識測驗 (Auditory discrimination tests)
  - 評估個案分辨相似聲音的能力
    - 頻率、音強、時間線索、調頻曲線tuning curve、音素等
- 聽覺時間處理與型態測驗 (Auditory temporal processing and patterning tests)
  - 評估個案分析聲音訊號隨時間變化的能力
- 雙耳異訊語音測驗 (Dichotic speech tests)
  - 雙耳異訊：兩耳同時聽到聲音，但聽到的聲音不同
  - 評估個案分離或統整聲音的能力

CAPD測驗類型 (ASHA, 2005)

- 單耳低冗贅口語測驗 (Monnaural low-redundancy speech tests)
  - 評估單耳辨識降階訊號的能力
- 雙耳互動測驗 (Binaural interaction tests)
  - 評估雙耳依據音強或時間差異處理聲音的能力
- 電聲測驗 (Electroacoustic measures)
  - 從耳道紀錄自發或被聲音誘發的反應
    - 耳聲傳射OAE、鐙骨肌反射閾AR threshold、鐙骨肌反射衰退AR decay
- 電生理測驗 (Electrophysiologic measures)
  - 紀錄中樞神經系統被聲音誘發的同步性電位反應

CAPD測驗選擇

- Because of the variability and the nature of the profiles of (C)APD, there exists no absolute gold standard for deriving sensitivity and specificity data for tests of central auditory dysfunction.
  - Documented reliability and sensitivity & specificity to known involvement of CANS
- Tests/test battery should provide
  - Norms appropriate for the patient being assessed
  - Assess several CAP and behaviors that might be affected
  - Considered patient symptoms and complaints
  - Behavioral + electrophysiological measures in combination might lead to increased sensibility

CAPD測驗結果的解釋

- CAP評估的目的/要回答的問題
  - CAPD是否存在？
  - 哪個(些)聽覺處理功能異常？
  - CANS的功能異常位置？
  - 結合教育、認知、口語/語言、社會及其他專業資訊後，CAPD類型？
- 評估➔介入管理計劃

CAPD測驗結果的解釋：確診

- 臨床常用的CAPD鑑定標準
  - 至少2項測驗的表現低於平均2個標準差，或者
  - 有1項測驗的表現低於平均3個標準差
- 選擇鑑定標準的難處與問題
  - 是否忽略掉單一聽覺處理困難者？
  - 行為表現相同者，聽覺處理困難一定相同？
  - CAPD普及率？ 7.3%~96% (Wilson & Arnott, 2013)
- 考量日常生活或教育環境中的影響

CAPD測驗結果的解釋：聽覺處理功能異常

- ➢Auditory closure 聽覺閉鎖缺失
- ➢Binaural separation and binaural integration雙耳分離與整合缺失
- ➢Temporal patterning 時間型態缺失
- ➢Binaural interaction 雙耳互動缺失
- ➢其他

(Bellis, 2011)

CAPD測驗結果的解釋：聽覺處理功能異常

➢Auditory closure 聽覺閉鎖缺失

- 聆聽者使用內在或外在冗贅線索來填補遺漏或扭曲的聽覺訊號

主要特徵	行為表現	測驗結果	療育建議
中樞聽覺系統的內部冗贅產生問題 • 單耳分離 • 聽覺辨識 • 聽覺解碼 • 更基礎的可能來源：時間處理	當聽覺訊號有部份成份遺漏時，有克漏困難。 • 接聽電話 • 噪音中聆聽	單耳低冗贅語音測驗表現差。 • Low-pass filtered speech • Time-compressed speech • Speech in noise	改善聲學可及性；預教新概念及詞彙；音素聽辨訓練；教導補償策略以加強由上而下技能。

CAPD測驗結果的解釋：聽覺處理功能異常

➢Binaural separation and binaural integration雙耳分離與整合缺失

主要特徵	行為表現	測驗結果	療育建議
雙耳分離：難以處理一耳的訊息同時，忽略另一耳的競訊。 雙耳整合：難以處理同時傳至雙耳的訊息與雙耳互動不同	• 噪音中聆聽有困難(也是聽覺閉鎖缺失的行為特徵) • 同時多人說話時有理解困難。	雙耳異訊語音測驗表現差。 • 自由回想作答模式：雙耳整合 • 指定耳作答模式：雙耳分離	改善環境中的聲學可及性；教導補償策略如：引導注意力；雙耳異訊聆聽訓練。

CAPD測驗結果的解釋：聽覺處理功能異常

➢Temporal patterning 時間型態缺失

主要特徵	行為表現	測驗結果	療育建議
難以辨識聲學輪廓，如節奏(rhythm)、重音、語調/聲調 • 辨識 • 排序 • 整體型態知覺 • 記憶	無法辨識與使用語音的韻律特徵 • 擷取關鍵字有困難 • 朗誦或說話時聲調平 • 聲音排序可能有問題(段落層面或字詞層面)	不管是以語言指稱或是以哼唱方式，時間型態測驗表現都異常。 • 音高型態測驗FPT • 時長型態測驗DPT	關鍵字擷取訓練；韻律訓練；時間型態訓練；以誇張的韻律特徵大聲朗誦。

CAPD測驗結果的解釋：聽覺處理功能異常

➢Binaural interaction 雙耳互動缺失

主要特徵	行為表現	測驗結果	療育建議
腦幹處理雙耳線索有問題 • 聲源辨位與側化 • 雙耳遮蔽解除 • 噪音中察覺訊息 • 雙耳融合	• 難以辨認音源或側化 • 聆聽噪音中的訊息有困難	• 遮蔽差異值測驗結果異常 • ABR異常 • 雙耳融合測驗結果異常	改善環境中的訊噪比；音源辨識訓練；側化與選擇性聆聽訓練；聽覺閉鎖策略；轉介以排除耳蝸後病理。

CAPD測驗結果的解釋：聽覺處理功能異常

➢其他：Temporal processing時間處理缺失

- 時間解析測驗異常：如隨機間隔察覺測驗(RGDT)
- 單耳低冗贅語音測驗表現差 (特別是時間壓縮語音測驗)
- 最明顯的行為表現是處理語速快的訊息有困難
- 建議：降低語速

CAPD測驗結果的解釋：聽覺處理功能異常

- 其他：Auditory discrimination聽覺分辨
  - 分辨聽覺訊息的異同
  - 生活中許多聽覺行為都依賴的能力
  - 語音辨識可能造成的困難
    - 安靜與噪音情境中的字詞辨識與口語理解
    - 聽覺閉鎖能力
    - 雙耳分離、整合或互動測驗都可能異常
  - 音韻覺識可能異常
  - 可利用事件相關電生理測驗(MMN)或心理聲學測驗(just noticeable differences, JND)佐證
  - 建議：直接訓練、環境調整、由上而下的聽覺閉鎖補償策略

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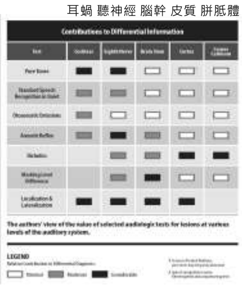
CAPD測驗結果的解釋：CANS的功能異常位置

- 腦幹
- 大腦
- 半腦間 (胼胝體)

耳蝸 聽神經 腦幹 皮質 胼胝體



(Musiek et al., 2018)

耳蝸 聽神經 腦幹 皮質 胼胝體

小　普通　大
(鑑別診斷的貢獻)

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CAPD測驗結果的解釋：CAPD亞型

- Buffalo Model 水牛城模式 (Katz et al., 1994)
  - 依據測驗庫中檢視聽覺處理不同面向的三項測驗結果，將個案表現與各測驗的測量指標對照，診斷CAPD 及其代表的問題亞型。
    - Staggered Spondaic Word (SSW)
    - Phonemic Synthesis (PS) test
    - Speech-in-Noise test (e.g. W-22 words in noise)
  - CAPD亞型
    - 解碼亞型(Decoding Category)
    - 容受-記憶衰退亞型(Tolerance-Fading Memory Category, TFM)
    - 統整亞型(Integration Category)
    - 組織亞型(Organization Category)

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CAPD測驗結果的解釋：CAPD亞型

- Bellis/Ferre Model (Bellis, 1996, 1999; Bellis & Ferre, 1999; Ferre, 1997)
- 發展概念：連結測驗結果與其潛在的神經生理基礎以及產生在行為/認知/學業/溝通上的結果
- 前3類為主要亞型，對應到生理上的特定位置；後2類為次要亞型，處在聽覺問題和更高層次之間的模糊界線。
  - 聽覺解碼缺失(Auditory Decoding Deficit)：左半腦功能異常(初級聽覺皮質)
  - 韻律缺失(Prosodic Deficit)：右半腦功能異常
  - 整合缺失(Integration Deficit)：跨腦半球路徑功能異常
  - 聯結缺失(Associative Deficit)：聽覺連結區；行為呈現口語理解問題
  - 輸出-組織缺失(Output-Organization Deficit)

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CAPD的介入與管理

- 全面性的療育計畫應根據兒童的個別化資訊擬訂，並儘可能**針對異常/缺失**來設計, 也就是奠基在兒童的聽覺優勢上，修復功能異常的聽覺領域。
- 療育計畫必須考量到對行為、教育和溝通結果的影響，才能達到最理想的功能性效益。
- 所以，**CAPD療育計畫在本質上必須是多專業服務模式**，專業人員可能包含語言治療師、心理師、聽力師、神經心理師、學習障礙專業人員、社工、老師、父母和其他可能參與照護孩子過程的人員。

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CAPD的介入與管理

- 環境調整(environmental modifications)：目的在於改善兒童對聽覺訊息的接收
- 矯正技術(remediation techniques)：目的在於加強辨識、半球間訊息的轉移，以及相關的神經聽覺功能
    - BSA (2018): Auditory training
      - Interactive training devices, e.g., LiSN & Learn, Memory Booster, Earobics, Earobics, FastForWord
      - Musical Training
- 補償策略(compensatory strategies)：目的在教導兒童如何克服聽覺處理異常並極盡所能利用聽覺訊息

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114年中樞聽覺處理異常研習

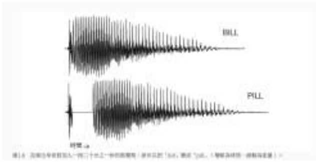
時間處理類型測驗及施測說明

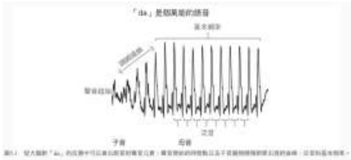
張憶萍聽力師

婦聯聽覺健康社會福利基金會
National Women's League Hearing Health Foundation

聽覺時間處理

- Perception of sound or the alteration of sounds within a restricted or defined time domain (Musiek et al., 2005)
- Perception of time varying sounds (Moore, 2003)





（圖片來源： Nina Kraus，大腦這樣聽）

時間處理類型

- 時間順序 (temporal ordering or sequencing)
- 時間解析或分辨 (temporal resolution or discrimination)
- 時間統整或總合 (temporal integration or summation)
- 時間遮蔽 (temporal masking)

聽覺時間處理

- 功能上的缺失
  - Lack of prosody during speech and reading aloud
  - Poor emotional tone
  - Difficulty understanding poetry
  - Difficulty understanding jokes
  - Deficits to segment words in the sentence
  - Comorbid presentation of CAPD and reading and spelling deficits

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聽覺時間處理功能異常位置

- Temporal processing appears dependent primarily on cerebral 大腦 and interhemispheric 半腦間 processing (Pinherio & Musiek, 1985)

時間順序 (Temporal ordering or sequencing)

- 處理2個(含)以上的聲音訊息在時間向度的順序
  - 被廣泛探討的現象
    - 語音知覺的重要性
  - 需要結構和生理上完整的左、右半腦和胼胝體
    - 動物模型
    - 腦傷病人
      - 顳葉病灶
      - 裂腦(胼胝體損傷)

時間順序 (Temporal ordering or sequencing)

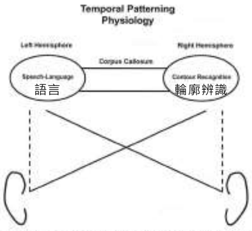


Figure 15–1. Illustration of the physiological mechanisms required for temporal patterning. Contour recognition occurs in the right hemisphere and information is transferred across the corpus callosum to the left hemisphere where linguistic process occurs.

(Musiek & Chermak, 2014)

時間順序 (Temporal ordering or sequencing)

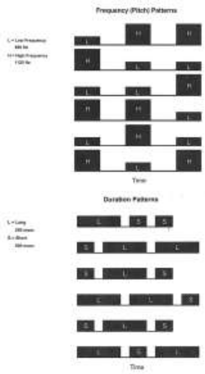
- 影響測驗結果的受試者和刺激音因素
  - 練習/訓練
    - 時間處理技巧高度可訓
  - 刺激音類型：純音、噪音、click、語音
  - 刺激音數目
  - 刺激音時長：與時間統整有關
  - 速度：刺激音間隔時長

時間順序測驗：型態測驗

- 頻率/音高型態測驗 (Frequency Pattern Test, FPT或Pitch Pattern Test, PPT)
  - Pinheiro and Ptacek in 1971
- 時長型態測驗 (Duration Pattern Test, DPT)
- 受試者要依序命名聽到的3個純音
- 優點
  - 容易施測
  - 敏感度及特異度佳 (針對大腦病灶，對腦幹病灶的敏感度則較低)
  - 8歲以上兒童適合 (尤其是FPT)

時間順序測驗：型態測驗

- 施測材料
  - FPT：由高、低頻純音組成的3音組
    - 6種組合型態 (去除高-高-高與低-低-低音組)
  - DPT：由長、短純音組成的3音組
    - 6種組合型態 (去除長-長-長與短-短-短音組)
- 作答方式
  - 命名 (FPT：「高」或「低」、DPT：「長」或「短」)
  - 若無法命名則用哼唱
- 計分：辨識正確率



(Musiek & Chermak, 2014)

時間順序測驗：型態測驗

- 結果 (常模範例Bellis, 2003)
  - 老化可能影響結果➔另發展常模
- 倒反：建議計為錯誤
  - 高低顛倒、長短顛倒
- 雙耳間差異：無
- 周邊聽損影響：確保音量足夠情形下，不受輕至中度聽損影響 (尤其是DPT)
- 測驗難度：DPT > FPT，顯示兩者不可互相交替

Table 15–1A. Normative Values for the Frequency Pattern Test Based On Two Standard Deviations Below the Mean.

Age	Normative Value
7	35%
8	42%
9	63%
10	78%
11	78%
12	80%

Source: Bellis, 2003.

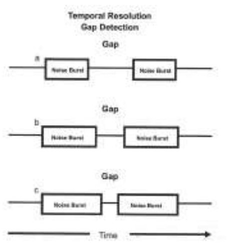
Table 15–1B. Normative Values for the Duration Pattern Test Based On Two Standard Deviations Below the Mean.

Age	Normative Value
7	25%
8	35%
9	54%
10	70%
11	71%
12	73%

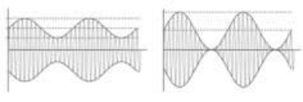
Source: Bellis, 2003.

時間解析或分辨 (Temporal resolution or discrimination)

- 時間向度中分辨聲音變化所需的最短時間或最小變化程度



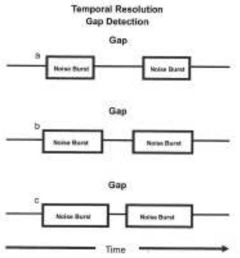
(Musiek & Chermak, 2014)



(www.electronics-notes.com)

時間解析測驗：隨機間隔察覺測驗

- Random Gap Detection Test, RGDT
  - 頻道內處理 (within-channel processing)
  - 受試者要回答聽到1個聲音還是2個聲音➔察覺聲音之間的間隔
  - 500, 1000, 2000, 4000 Hz純音、寬頻click
  - 間隔時長為0~40 msec (延長組間隔時長為50~300 msec)
  - 間隔察覺閾 (gap detection threshold)：察覺間隔所需的最短時長



(Musiek & Chermak, 2014)

時間解析測驗：隨機間隔察覺測驗

- 結果

Table 1. MEAN AND STANDARD DEVIATION OF NORMAL RANDOM GAP DETECTION THRESOLDS AND SUGGESTED CUT-OFF SCORES

AGE (Years)	Normal Mean (msec)	Std. Dev.	Cut off*
5-7	7.3	4.8	20
8	6.0	2.5	20
9	7.2	5.3	20
10-11	7.8	3.9	20

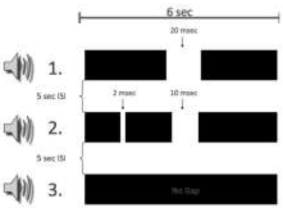
- 對皮質病灶敏感，尤其是左顳葉
- 周邊聽損影響：不大 (也有反例)
- 時間解析處理的成熟：早、對稱
- 老化造成影響 (無周邊聽損)

Table 2. MEAN AND STANDARD DEVIATION OF NORMAL AFT[illegible] AND SUGGESTED CUT-OFF SCORES

AGE (Years)	Normal Mean (msec)	Std. Dev.	Cut off*
5	15	5	25
6	12	4	20
7	9	4	20
8-59	6	3	20
60	9	8	25
79	22	17	50

時間解析測驗：噪音中間隔察覺測驗

- Gap in noise (GIN) test
  - 持續6秒的寬頻噪音
  - 0~3個間隔
  - 受試者聽到間隔就要反應



(Musiek et al., 2005)

時間解析測驗：噪音中間隔察覺測驗

- Gap in noise (GIN) test
  - A.th (approximate threshold)-the shortest gap duration for which there are at least 4 of 6 correct identifications.
  - % correct-correct responses out of the total number of gaps
  - Norm-no developmental effect seen in children btw age 7 and 18. No ear asymmetry is observed.

Threshold	2 msec	3 msec	4 msec	5 msec	6 msec	8 msec	10 msec	12 msec	15 msec	20 msec	Total % Score
List 1	0 /6	1 /6	3 /6	4/6	6 /6	6 /6	6 /6	6 /6	6 /6	6/6	45/60
Left Ear	0%	17 %	50 %	67 %	100 %	100 %	100 %	100 %	100 %	100 %	75%
				X							

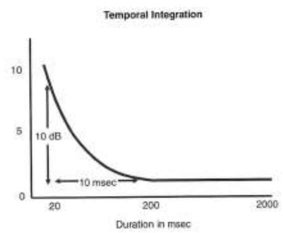
A.Th = 5 msec

75% Correct

(Musiek et al., 2017)

時間統整或總合 (Temporal integration or summation)

- 聽覺系統在一段時間內累積聲音能量或訊息的能力
- 聲音越長，察覺閾會降低，直到時長達200 msec



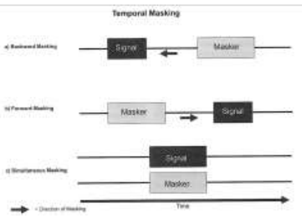
(Musiek & Chermak, 2014)

時間統整或總合 (Temporal integration or summation)

- CAPD(顳葉病灶)個案的時間統整或整合處理
  - 對側耳聆聽短純音的頻率差異閾(frequency difference limen)提高
  - 對側耳的極短純音察覺閾提高程度更明顯
- 目前沒有相關臨床工具

時間遮蔽 (Temporal masking)

- 聲音訊號和遮蔽音未同時出現時，聲音訊號察覺閾變化
- 後遮蔽 (backward masking)：遮蔽音在聲音訊號後面
- 前遮蔽 (forward masking)：遮蔽音在聲音訊號前面



(Musiek & Chermak, 2014)

時間遮蔽 (Temporal masking)

- 機制未明
  - 周邊&中樞；兩者不同 (後遮蔽可經訓練後改善、較易受注意力和認知能力影響等)
- 影響參數：聲音訊號與遮蔽音之間的間隔、遮蔽音音量、遮蔽音長度、聲音訊號與遮蔽音的聲學相似度
- 後遮蔽的遮蔽效果較大
- 同側遮蔽效果較對側遮蔽大
- 兒童受後遮蔽的影響較成人大 (應該與時間解析能力無關)
- 目前沒有相關臨床工具

操作時間

114年中樞聽覺處理異常研習

雙耳互動測驗及電生理測驗介紹

張憶萍聽力師

婦聯聽覺健康社會福利基金會
National Women's League Hearing Health Foundation

雙耳互動 (Binaural Interaction, BI)

- 雙耳合作的方式
- 雙耳聆聽的優勢
  - Binaural summation雙耳積合
    - 聲音強度與敏感度提升：↑3 dB in threshold, 10-20% in loudness
  - Binaural redundancy雙耳冗贅
  - Spatial hearing空間知覺
    - 聲源定位(localization)與側化(lateralization)
  - 噪音中聆聽
    - 雙耳遮蔽解除(release from masking)
  - 雙耳融合(binaural fusion)

雙耳互動 (Binaural Interaction, BI)

- Present at birth, but immature.
- Postnatal maturation is experience dependent and reduced or altered cochlear output during the early postnatal period may change the normal development of CANS.

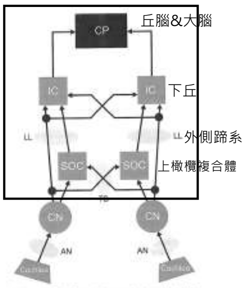
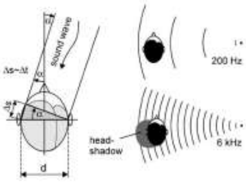


Figure 16-1. Schematic representation of the main brainstem nuclei of the auditory pathway and their main connections. AN = auditory nerve, CN = cochlear nucleus, SOC = superior olivary complex, LL = lateral lemniscus, IC = inferior colliculus, CP = central processor.

(Musiek & Chermak, 2014)

雙耳互動：定位與側化

- 雙耳時間差 (interaural time difference, ITD)
  - 主要：MSO內側上橄欖核，次要：IC下丘、MGB內側膝狀體
  - 作用於低頻
- 雙耳音量差 (interaural level difference, ILD)
  - 主要：LSO外側上橄欖核，次要： NLL外側蹄系, IC下丘、MGB內側膝狀體
  - 作用於高頻➔頭影效應
- 單耳的聲源辨識
  - 聲音本身的頻譜(spectral)特性和時間(temporal)特性、頭/耳/身體



(Willert et al., 2006)

雙耳互動：雙耳遮蔽解除 (Release from masking)

- 噪音遮蔽聲音訊息的狀況解除，使得聲音訊息的察覺閾提升
- Licklider (1948)首次研究此現象
- S：聲音訊號；N：噪音/遮蔽音
- Ø：0度角相位；π： 180度角相位
- 同相位(homophasic)：$S_{\varnothing}N_{\varnothing}$、 $S_{\pi}N_{\pi}$
- 反相位(homophasic)：$S_{\varnothing}N_{\pi}$、 $S_{\pi}N_{\varnothing}$
  - 雙耳遮蔽解除，聲音訊息閾值降低

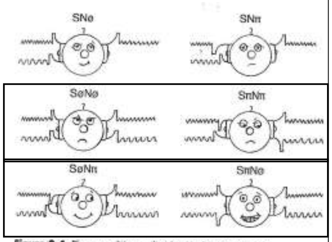


Figure 2-4. Phase conditions utilized in Hirsh's (1948) study.

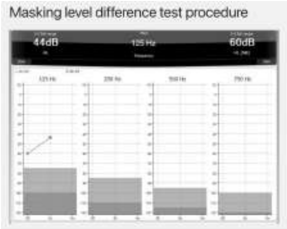
(Bellis, 2011)

雙耳互動測驗(Binaural Interaction, BI)

- 評估中樞聽覺系統處理傳入雙耳不同但互補的訊息的能力
- 適合主訴：辨識聲源有困難、噪音中聽有困難
  - 雙耳異訊測驗
- 與雙耳異訊測驗的不同
  - 聲音非同時提供，或者
  - 單耳只聽到完整訊息的一部份，因此聽者需要整合雙耳訊息
- 雙耳互動：低腦幹功能
- 雙耳互動測驗對腦幹病灶敏感
  - 皮質異常以及由上而下處理的影響
  - 周邊聽損的影響

雙耳互動測驗：遮蔽差異值 (Masking Level Difference, MLD)

- MLD定義： $S_{\emptyset}N_{\emptyset}$的察覺閾 - $S_{\pi}N_{\emptyset}$的察覺閾
- Signal：純音或語音 (如spondees同調號雙字詞)；Noise：寬頻噪音
- 施測流程
  - 噪音固定音量，訊號以2 dB間隔降低
  - 先找出$S_{\emptyset}N_{\emptyset}$的察覺閾
  - 再找出$S_{\pi}N_{\emptyset}$的察覺閾



(www.interacoustics.com)

雙耳互動測驗：遮蔽差異值 (Masking Level Difference, MLD)

- 結果
  - 影響參數：刺激音(純音頻率、語音)、遮蔽音類型
  - 年齡：兒童<成人，老年族群的結果不一
  - 周邊聽損：會影響MLD
    - 甚至到聽力恢復後還會持續影響一陣子➔有OME中耳積水案史者(but listening difficulty might still persist)
    - 不對稱聽力
  - 異常MLD
    - 有低腦幹病灶者；MS多發性硬化症者
    - 讀寫障礙兒童 (dyslexia)

雙耳互動測驗：快速交替語音知覺測驗 (RASP)

- Rapidly Alternating Speech Perception, RASP
- 句子以固定間隔時間快速於雙耳間來回播放
- 以Willeford 1977發展的RASP測驗為例
  - 每句約7個字
  - 交替速率：300ms
  - 播放音量：40 dB SL re: PTA
  - 10句先從左耳播放、10句先從右耳播放

Figure 16–4. Illustration of the Rapidly Alternating Speech Perception (RASP) test.

(Musiek & Chermak, 2014)

雙耳互動測驗：快速交替語音知覺測驗 (RASP)

- 周邊聽損會影響結果
- 測驗難度
  - 可施測於年紀較小的兒童
- 測驗效度 (efficiency)
  - 對腦幹病灶的敏感度低
- 臨床使用度低
  - ABR & MLD對腦幹病灶的效度較高

雙耳互動測驗：雙耳融合測驗

- Binaural Fusion Test
  - 雙耳聆聽帶通過濾(band-pass filtered)語音；一耳聆聽低通過濾(low-pass filtered)訊息、一耳聆聽高通過濾(high-pass filtered)訊息
    - 例如：500-700 Hz低帶通與1900-2100高帶通、500 Hz以下低通與3000Hz以上高通
  - 雙耳聆聽單音節字詞，一耳只聽到子音，一耳只聽到母音
  - 雙耳異訊

Figure 16–5. Illustration of the binaural fusion paradigm.

(Musiek & Chermak, 2014)

雙耳互動測驗：雙耳融合測驗

- 以NU-6雙耳融合測驗為例
  - 材料：子音-母音-子音(CVC)單音節字詞
    - 一耳低通、一耳高通
  - 音量：30-35 dB SL re: 低頻PTA與高頻PTA
  - 計分：辨識正確率

NU-6 words found in samples and their occurrence

back	1	late	2	such	2	white	2
chief	1	love	1	take	3		
fail	4	make	1	tell	1		
fall	2	near	2	third	1		
far	1	note	2	thought	1		
get	2	rush	2	tough	1		
good	1	said	30	walk	1		
have	8	sail	1	week	2		
home	1	sell	2	when	8		
kill	1	south	1	which	3		

(Thomson, 2002)

雙耳互動測驗：雙耳融合測驗

- 影響檢查結果的因素
  - 刺激音量，e.g., 86.6%@ 36 dB HL vs. 66.4%@ 30 dB HL using NU-6 word lists on adults (Smith & Resnick, 1972)
  - 周邊聽損
- 腦幹病灶個案呈現表現較差，皮質病灶病人則否
  - Dichotic (雙耳異訊) vs. diotic (雙耳同訊，雙耳同時聽到低通與高通的訊號)
- 部分讀寫障礙(dyslexia)與特定型語言障礙(SLI)兒童的雙耳融合測驗表現較差

雙耳互動測驗：LiSN-S

- Listening in Spatialized Noise-Continuous Discourse Test (Cameron, Dillon, & Newall, 2006) and then Listening in Spatialized Noise-Sentence Test (Cameron & Dillon, 2007)
- 與MLD相關性佳
- 利用特製電腦軟體+耳機創造虛擬立體聽覺空間➔4個情境
  - 句子出現在受試者正前方(0 degree)、競訊語音(兒童說故事的聲音)在左或右方(±90 degree)
  - 說話者聲音相同 vs.不同

LiSN−S (Cameron & Dillon, 2007)

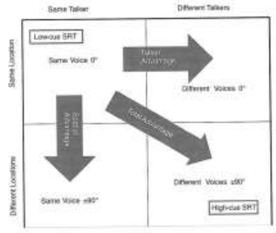


Figure 16–6. Illustration of the four listening conditions and derived "advantages" (spatial, talker, and total) of the LiSN-S. The listening conditions are: same voice target and competing speech at 0° azimuth (SV0), same voice at ± 90° azimuth (SV90), different voices at 0° azimuth (DV0), and different voices at ± 90° azimuth (DV90). From *Ear and Hearing*, by Cameron, S. & Dillon, H. 2007, Vol 28, Issue 2. Reproduced with permission from Wolters Kluwer Health.

(Musiek & Chermak, 2014)

雙耳互動測驗：LiSN-S

- 結果
  - 疑似CAPD兒童在空間優勢中有缺失
  - 有注意力或學習問題的兒童表現與常模相仿

雙耳互動測驗

- 雙耳互動缺失的主要特性

主要特徵	行為表現	測驗結果	療育建議
腦幹處理雙耳線索有問題	難以辨認音源或側化聲音線索，導致噪音中聆聽訊息有困難。	• 遮蔽差異值測驗結果異常 • ABR異常 • 雙耳融合測驗結果異常	• 改善環境中的訊噪比 • 音源辨識訓練 • 側化與選擇性聆聽訓練 • 聽覺閉鎖策略 • 轉介以排除耳蝸後病理

電生理(含電聲學)測驗

- Why include them?
  - Speech and language processing can be defined as neural operations responsible for transforming the acoustic characteristics of speech into a linguistic representation. 聽覺訊號處理 ➔神經運作
  - Obtaining information regarding the integrity of the CANS should improve the diagnosis of the disorder, assist in intervention programming and contribute to monitoring treatment outcomes. 獲得CANS的完整性有助後續介入及成效追蹤
  - Compared with behavioral tasks, many but not all electrophysiologic measured do not require the listener's active participation and are therefore more objective and can be reliably recorded from infants and very young children, less affected by confounds such as memory, language, motivation, and tasks, and response criteria and strategies. 客觀性評估

電生理(含電聲學)測驗

- ASHA (2005)將CAPD測驗分為7類，電生理測驗為其中一類
- AAA (2010)提出電生理應用的實務考慮
  - There are no widely accepted criteria as to when AERs should be included in the clinical evaluation of (C)APD.
  - There are no accepted protocols for AER measurement.
  - (There are) no evidence-based recommendations for stimulus and acquisition parameters.
  - Normative data acquired from large numbers of subjects across the lifespan are lacking for each of the major cortical AERs.
  - Routine application of AERs as a standard clinical procedure may not always be indicated.

電生理(含電聲學)測驗

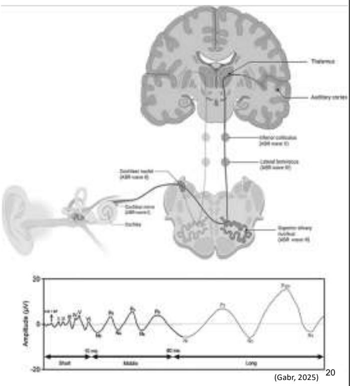
- 其他電生理應用的實務考慮 (Bellis, 2011)
  - 視個案評估需求而定
  - 多數CAPD個案的臨床常用電生理測驗結果正常
  - 電生理結果與聽覺行為問題之間的關聯？
  - 對後續介入策略幫助不多

電生理(含電聲學)測驗

- 考慮執行電生理測驗的時機(AAA, 2010)
  - Behavioral assessment fails to reveal a clear pattern of deficits
  - Behavioral test findings are incomplete or inconclusive or are compromised by selected listener variables (e.g., attention, motivation, cognitive status)
  - The age of a young child precludes comprehensive behavioral assessment of (C)APD using behavioral measures
  - A neurologic disorder requiring medical follow-up is suspected
  - Information on the site of dysfunction within the CANS is needed for individuals showing a clear pattern of (C)APD with behavioral assessment
  - Behavioral measures of (C)APD are not available in the individual's native language

電生理(含電聲學)測驗

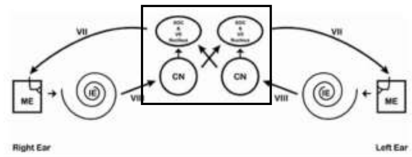
- 鐙骨肌反射Acoustic reflex
- 耳聲傳射的對側抑制 (contralateral suppression of OAE)
- 聽性腦幹腦幹反應ABR
- 頻率跟隨反應FFR
- 皮質聽覺誘發反應CAEP
- 不匹配負波MMN
- P300



(Gabr, 2025)

電生理(含電聲學)測驗：鐙骨肌反射檢查

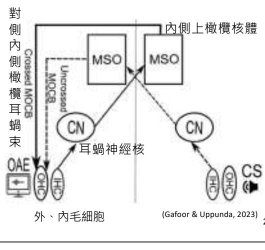
- 鐙骨肌反射路徑：含低腦幹部位
  - 同側：耳蝸➔聽神經➔腹側耳蝸神經核➔內側上橄欖複合體➔顏面神經➔鐙骨肌收縮
  - 對側：耳蝸➔聽神經➔腹側耳蝸神經核➔**<u>對側</u>**上橄欖複合體➔**<u>對側</u>**顏面神經➔**<u>對側</u>**鐙骨肌收縮
  - 也是周邊系統評估工具
  - ART, decay



(Emmanuel, 2009)

電生理(含電聲)測驗：耳聲傳射(OAE)的對側抑制

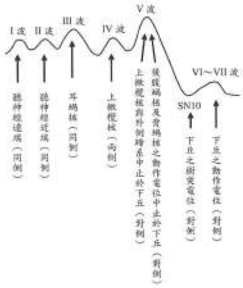
- 臨床OAE測驗為周邊聽覺系統的診斷工具
  - OHC功能
- TEOAE對側抑制的路徑涵蓋到低腦幹
  - 下行抑制路徑
  - 強化噪音中聆聽
  - Decreased MOCB activity in CAPD patients
    - 研究結果不一致
  - 臨床使用不普及
    - High variability



(Gafoor & Uppunda, 2023)

電生理測驗：ABR

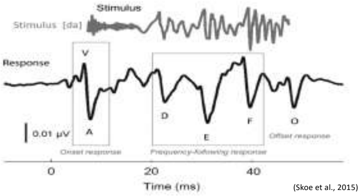
- 對腦幹病灶的診斷敏感度及特異度佳
  - Frank neurological lesion
- 較不受到認知、清醒狀態影響
- 2歲左右趨近成熟
- 多數CAPD個案的ABR是正常的
  - 刺激音click不具診斷性？異常部位在更高層？
- 長期中耳積水案史的個案即便症狀和聽力都恢復，III和V波仍出現延遲



(楊義良等人，2020)

電生理測驗：頻率跟隨反應FFR

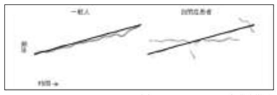
- Frequency Following Response (used to be Complex ABR, cABR)
  - 來源：中腦 (下丘)
- cABR-first used with speech in Auditory Neuroscience Lab (Brainvolts) in 2001
  - V & A
    - V = ABR Wave V, A = SN10
    - Response to stimulus onset
  - DEF
    - FFR
    - Reflecting pulsing of vocal cords
  - O
    - Offset response



(Skoe et al., 2015) 24

電生理測驗：頻率跟隨反應FFR

- 分析
  - Timing Information: Peak Latency 潛時值
  - Accuracy/Consistency/Repeatability of Responses 反應一致性、相關性
    - Cross correlation of Response
    - Cross correlation of Response to Stimulus
    - Cross correlation of Response to other condition response
    - Fsp/Fmp values with block averaging
  - Monitor neural signature stability or fidelity through time
  - FFT: Frequency and Magnitude(strength): 頻率反應
    - Fundamental Frequency (F0)
    - Harmonics
  - Pitch F0穩定性追蹤
  - Phaseogram 時間差異
  - Spectrogram 噪音、訊噪比



（圖片來源： Nina Kraus，大腦這樣聽）

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電生理測驗：頻率跟隨反應FFR

- Brainstem responses to complex sound stimuli are altered (latency delay and lower amplitudes) in children with learning disabilities and CAPD.
  - Also F0 tracking, frequency-modulation sweep
- FFR綜合行為檢查結果，可能可找出不同層次的中樞聽覺處理問題，或可支撐行為檢查結果。

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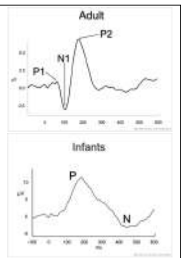
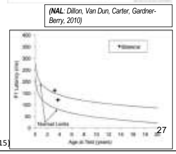
電生理測驗：皮質聽覺誘發反應CAEP

- 3 components: P1-N1-P2
  - A single peak for small children
- P1: primary auditory cortex and thalamus
- N1-P2: cortical-cortical circuits, thalamo-cortical pathways, and secondary auditory cortex
  - N1: onset response (皮質聽到聲音)



(NAL: Dillon, Van Dun, Carter, Gardner-Berry, 2010)

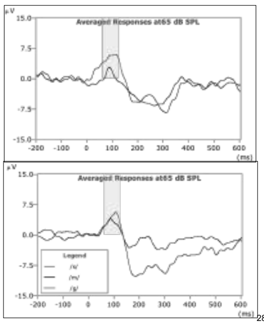


(Sharma et al., 2015)

27

電生理測驗：皮質聽覺誘發反應CAEP

- CAEP應用於CAPD
  - 相較於聽常兒童，CAPD兒童的N1、P2、P3潛時值較長，P2和P3的波間潛時值也更長 (Jirsa & Clontz, 1990、Jirsa, 1992)
    - 也有研究結果未見差異



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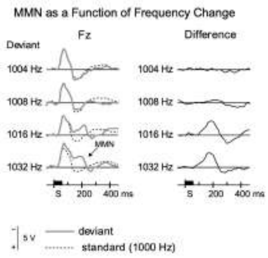
電生理測驗：不匹配負波MMN

- 違反聽覺規律引起的腦電圖負偏轉電位 ➔N2a波
  - 聆聽者不需專注於目標刺激，不受意識控制
  - 顳葉及前額葉區的神經網絡自動偵測與察覺到聽覺變化所產生的反應
- 研究發現MMN是發展遲緩的早期生物標記，包括CAPD
  - 也有研究結果未見差異



(Näätänen et al., 2007)

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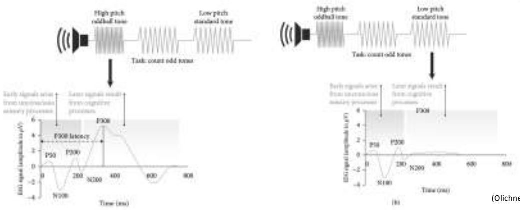
電生理測驗：P300

- P3波，尖峰潛時值約300ms
- 聆聽者需關注不頻繁出現的目標刺激音+任務，如：聽到目標刺激音就按按鈕，屬事件相關電位



(Olichney et al., 2022)

電生理測驗：P300

- 應用於CAPD
  - 兒童：P300潛時值較晚 (Jirsa & Clontz, 1990)
  - 成人：P300潛時值較晚 (Krishnamurti, 2001)

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