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研究計畫

整合隨機共振刺激和專用的互動式體感遊戲以提高老人的姿勢控制能力

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摘要

本計畫運用視覺隨機共振光刺激增進視覺感受性，並結合適當動作認知難度的「體感復健訓練遊戲」，一方面提高視覺與本體感覺等感覺訊息接受與整合能力，另一方面也兼顧老年人活動與趣味性的需求。本計畫開發的系統對促進人體平衡功能與改善人體平衡功能障礙在臨床研究及訓練上將有重大的助益。第一年計畫主要設計一個頭戴式次閥值的隨機白雜訊 LED 光刺激器刺激受試者雙眼，量測受試者的視覺誘發電位變化是否會出現非對稱倒 U 形的增益曲線，以量化隨機共振效應在受試者的感知訊息量與光刺激白雜訊強度間的關聯性，做為後續研究視覺隨機共振刺激對視覺感受性提升的實證基礎。此外，利用電腦設計出三維空間不同清晰度、不同形式、不同移動速度的目標物件，以眼球追蹤儀量測受試者眼睛凝視點位置、凝視點數目、平均凝視時間、平均跳躍眼動長度、凝視軌跡分布和凝視軌跡總長度等，作為評估視覺隨機共振刺激是否有改善受試者視知覺能力客觀指標。第二年計畫利用 Kinect 開發適當老年人的走迷宮遊戲、拍球遊戲、躲避球遊戲與踢足球等體感遊戲，用於老年人作視覺運動統合訓練、雙重作業認知協調訓練與雙重作業動作協調訓練。在作視覺運動統合訓練與雙重作業訓練的同時，利用眼球追蹤儀量測眼球運動的相關參數，作為評估視覺運動統合訓練成效的依據，並用於分析受試者如何凝視（視覺掃描）遊戲中出現的物件（如障礙物、球），在相關物件出現時，受試者如何依序規畫動作的執行以控制遊戲中所扮演的虛擬人物（如抬腳跨越障礙物、揮手拍球），從中瞭解受試者姿勢控制採用的策略。

關鍵詞：姿勢控制、隨機共振、體感遊戲

1. 研究背景

身體姿勢的控制系統是由感覺系統、運動系統和中樞神經系統互相協同作用而成。其中，身體姿勢控制的感覺系統包含三個主要的感覺受器，分別用來感知維持身體姿勢控制的相關訊息，分別為(1)視覺受器：提供身體在空間相對位置的訊息給大腦；(2)前庭覺受器：是位於中耳內三條相互垂直的半規管，提供頭相對於軀體在三個不同方向的運動平衡訊息；(3)本體感覺受器：分佈於身體體表與骨骼肌上，負責感知身體各肢結間的相對位置。上述感覺受器所感知的訊息輸入至大腦，經整合判斷處理後由大腦皮質的動作區域輸出動作訊息，再控制肌肉收縮與關節活動以維持穩定

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的姿勢控制(Peterka, 2002; Judge, 2003)。

對於年長的老人，隨著年齡的增長，半規管內感受器的毛細胞數目減少，初級前庭神經元衰退，造成前庭興奮性逐漸變差，影響前庭覺對姿勢的控制(Rosenhall, 1973; Richter, 1980)；在視覺方面，老年人的視覺清晰度、視野範圍、瞳孔的調節能力，亦隨著年齡增長而下降，致使老年人視覺搜尋(visual scanning)與物體辨識能力變差，許多研究顯示：老年人在較昏暗的環境因視覺辨識障礙而產生跌倒事故(Appelros et al., 2003; Reed-Jones et al., 2012)。此外，本體感覺能力亦隨年齡的增長而退化，造成老年人姿勢控制能力減弱(Peterka, 2002)。Peterka 等人的研究發現，老年人的姿勢穩定度受感覺回饋訊息減弱的影響極大，當視覺、前庭感覺和本體感覺其中任兩項訊息減弱時，姿勢穩定度大幅下降，如身體擺動增加、動作遲緩、步態不穩、協調能力減弱及動作精確度下降等，顯示感覺運動統合能力隨年齡增加而減弱，因而引起老人行動不便或是致命的跌倒意外的發生(Peterka et al.,1990; Laughton et al., 2003)。根據行政院衛生署國民健康局的統計，跌倒是老人罹病與死亡的重要原因（行政院衛生署，2009）。因此，尋求有效的方法增強人體感覺認知的敏感度，進而提升身體的姿勢控制能力以達到減少跌倒的發生率，具有重要的實質意義。

然而，如何增強老人感覺認知的敏感度，Collins 和 Priplata 等人的研究顯示(Collins et al., 2003; Priplata et al., 2002, 2003, 2006; Harry et al., 2005)，足部的次閾值(subthreshold)微弱隨機刺激（外加機械振動或電刺激），可以增強從足部傳向大腦的微弱訊息，這種效應稱做「隨機共振(stochastic resonance)」(Winterer et al., 1999; Moss et al., 2004; Harry et al., 2005; Todorov et al., 2005)。如圖 1 所示，人體感覺系統遵循全有或全無定律，當外加於人體感覺系統的刺激訊息低於閥值時，大腦無法感知此微弱的刺激訊息；只有當刺激的訊息高於閥值時，大腦才能感知此刺激訊息。但是當刺激訊息和低強度的次閥值隨機白雜訊(white noise)一同作用於系統時，閥值下的刺激也有可能引起中樞神經系統感知此刺激訊息。所以由於年齡和疾病，造成感知功能的衰退，導致了感知閥值的上升，過去曾經在閥值以上的刺激現在卻在閥值之下，所以對於老人以及特殊疾病的患者無法正常感知到外來刺激，導致大腦無法做出正確的決策來控制身體的平衡，因而有高的跌倒風險(Collins, 2003; Priplata et al., 2002, 2003, 2006)。

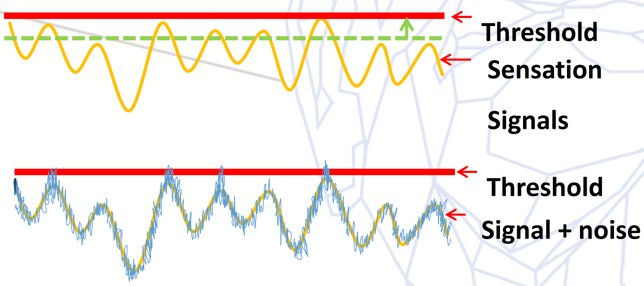

圖 1. 隨機共振增強感覺的概念

利用隨機共振的特性，生理學家成功從動物實驗發現，皮膚感受器、Ia、II、Ib 等輸入感覺神經的都出現雜訊調節感覺程度的現象(Fallon & Morgan, 2004; Fallon et al., 2005)。由於這些與動作功能有關的感受器是雜訊可調節的，運用低強度感覺刺激引發隨機共振，從感覺增益促進人體動作

功能便是一種可行的方向(Collins et al., 2003)；許多研究證實於關節處或足底位置提供低強度的刺激雜訊可以增強本體感覺的感受性，對於老年人、有周圍神經病變的糖尿病患、截肢者和中風患者，都可以明顯減少姿勢性的晃動並改善站立平衡能力(Dhruv et al. 2002; Gravelle et al., 2002; Liu et al., 2002; Priplata et al., 2002, 2003, 2006; Lee et al., 2009)。此外，相關研究證實，隨機共振亦能促進視覺的感受性，Ditzinger 等人(2000)研究在三維立體圖形視覺實驗中發現，隨機共振能夠提高視覺的感受性，讓人眼對於 3 維立體圖形深度的感知更敏銳。Sasaki 等人(2006, 2008)研究發現利用隨機共振技術可以增強視覺對影像信號的對比檢測。Leopold 等人研究發現利用隨機共振技術可以強化人眼對模糊影像的辨識度(Leopold et al., 2002; Piana et al., 2000)。特別是視覺隨機共振技術對於老年人姿勢平衡有潛在功能性的助益，可以協助視覺訓練提升老年人的視覺靈敏度(Reed-Jones et al., 2012)，這是過去對於老年人姿勢平衡訓練鮮少被重視的一環；然而藉由感覺隨機共振感覺刺激改進動作功能的詳細神經機制仍然不是十分明瞭（例如隨機共振如何造成感覺動作統合(sensorimotor integration)）；然而，隨機共振提高感覺神經的感受性，進而促進肌肉控制與動作功能的進步，已經被許多神經生理與復健學家認真思考其扮演動作復原的先驅價值。

另一方面，姿勢－上姿勢雙重作業(postural-suprapostural dual task)的研究證實了姿勢控制並非自動發生，而是牽涉複雜的大腦資源分配與注意力移轉課題(Beauchet at al., 2005; Bond & Morris, 2000; Braucer et al., 2002; Ebersbach & Dimitrijevic, 1995; Lajoie et al., 1993; Marsh& Geel, 2000; Rankin et al., 2000; Pelecchia, 2003, 2005; Silsupadol, 2006)。Lajoie 等人(1993)的研究利用雙重作業方法比較健康成年人坐著、站著或行走時對聲音訊號的反應，發現姿勢控制需要大腦注意力資源分配，較複雜、困難的姿勢控制所需的注意力多於簡單的姿勢控制。Pellecchia (2003, 2005)研究姿勢擺動是否會隨著同時進行的認知作業的難度而變化，結果顯示認知作業會影響姿勢擺動，越困難的認知作業對姿勢擺動的影響越大，由此可知注意力對姿勢控制的重要性。這說明為何平衡受損的老年人在走路時不會跌倒，但是在走路的同時說話或者做其他事情時，卻容易發生跌倒的原因。Silsupadol 等人(2006)研究老年人的三種平衡訓練方式的效果，分別為單作業訓練、固定優先注意某個作業的雙重作業訓練和不斷變換優先注意作業的雙重作業訓練。結果發現，雙重作業下的訓練效果可持續 3 個月，並且證實雙重作業訓練具有轉移作用。雖然雙重作業會影響姿勢的穩定性，但是選擇適當作業難度的雙重作業，其實更能增加姿勢的穩定度與訓練效果(McNevin & Wulf, 2002, Wulf et al., 2004)。另外，因為日常生活中姿勢活動往往是與其他姿勢上活動一起出現，在實際復健治療上，雙重作業的姿勢訓練比單純姿勢訓練更為重要；在學理上，經過雙重作業的訓練反而會啟動姿勢控制的內隱誘發(implicit facilitation)機制(Mitra et al., 1999, 2004)，姿勢作業受到姿勢上作業的競爭，規劃於姿勢與姿勢上作業的大腦資源(brain resource)大為擴張，繼而使分配於姿勢作業的大腦資源較同樣的單一姿勢作業所可以使用大腦資源為多(Huang & Hwang, 2011; Wulf et al., 2004)，因此姿勢表現更為穩定，姿勢作業得以更能有效訓練。

在復健醫學的應用方面，姿勢－上姿勢雙重作業模式的訓練可以改善受試者姿勢控制的能力，然而，傳統姿勢－上姿勢雙重作業的訓練較枯燥乏味，如走路時做算數運算或端盤子，影響訓練的動機與積極性。目前有許多電腦遊戲是藉由身體律動來操控，宛如身體即式控制器，讓人體動作與電腦遊戲密切結合，許多學者已將此類體感遊戲應用於老年人平衡的復健訓練，如任天堂 Wii fit 平

衡板(Sugarmanet al., 2009; Clark et al., 2010; Young et al., 2011; Kennedy et al. 2011; Pluchino et al., 2012)、微軟 Kinect (Chang et al., 2011; Lange et al., 2011)，透過遊戲化的方式進行復健訓練，可將枯燥乏味的重複復健訓練行為，變成吸引老年人的有趣活動，可提升老年人復健運動的意願，增加復健的效果。此外，體感遊戲亦應用於中風患者(Deutsch et al., 2009; Loh et al., 2010)、腦性麻痺兒童(Deutsch et al., 2008)、後天腦損傷患者(Gil-Gomez et al., 2011)的復健訓練，用途相當廣泛。然而什麼形式與內容的體感遊戲才符合復健訓練所需(Annema et al., 2010)，目前而言仍然需要更多的工程領域與復健醫學領域的專家學者們投入相關的研究。

2. 研究目的

本計畫目的是結合「視覺隨機共振刺激」與適當動作認知難度的「體感復健訓練遊戲」之老年人姿勢控制的訓練與評估系統並進行臨床實驗。其中，視覺隨機共振刺激可以增強老年人視覺敏銳性，適當動作認知難度的互動式體感遊戲可以提高老人復健訓練的趣味，吸引老年人進行視覺運動統合訓練、雙重作業認知訓練與雙重作業動作訓練的意願，兩者結合可以促進老年人視覺敏銳性，協助老年人發展出適當大腦注意力資源配置，增進感覺動作統合協調的能力與提升老年人姿勢控制的能力。第一年研究計畫主要是設計一個頭戴式次閥值的隨機白雜訊 LED 光刺激器刺激受試者雙眼，量測受試者的視覺誘發電位變化是否會出現非對稱倒 U 形的增益曲線，以量化隨機共振效應在受試者的感知訊息量與光刺激白雜訊強度間的關聯性，做為後續研究視覺隨機共振刺激對視覺感受性提升的實證基礎。此外，利用電腦設計出 3 維空間不同清晰度、不同形式、不同移動速度的目標物件，以眼球追蹤儀(eye tracking system)量測受試者眼睛凝視點位置、凝視點數目、平均凝視時間、平均跳躍眼動(saccadic)長度、凝視軌跡分布和凝視軌跡總長度等，作為評估視覺隨機共振刺激是否有改善受試者視知覺能力的一項客觀指標。第二年研究計畫將利用 Kinect 開發適當老年人的走迷宮遊戲、拍球遊戲、躲避球遊戲與踢足球等體感遊戲，用於老年人作視覺運動統合訓練、雙重作業認知協調訓練與雙重作業動作協調訓練。在作視覺運動統合訓練與雙重作業訓練的同時，利用眼球追蹤儀量測眼球運動的相關參數，作為評估視覺運動統合訓練成效的依據，並用於分析受試者如何凝視（視覺掃描）遊戲中出現的物件（如障礙物、球），在相關物件出現時，受試者如何依序規畫動作的執行以控制遊戲中所扮演的虛擬人物（如抬腳跨越障礙物、揮手拍球），從中瞭解受試者姿勢控制所採用的策略。

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Integration of stochastic resonance stimulation and dedicated interactive motion sensing games to enhance the postural control abilities of the elderly

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Abstract

Postural instability in elderly people is a major contributor to falls. Stochastic resonance stimulation is a novel intervention which provides potential benefits for enhancing postural control ability of the elderly. Besides, motion sensing games make the elderly have higher willingness and motivation to perform rehabilitation training. However, commercial motion sensing games are not necessarily suitable for the elderly because the type of athletic activity makes older people feel nervous and frustrated. Dedicated motion sensing games used for rehabilitation need to cooperatively develop with physiotherapy scholar according to the requirements of the elderly. The aim of this two-year project is to integrate stochastic resonance electrical stimulation and dedicated interactive motion sensing games with entertaining rehabilitation programs to promote postural control ability of the elderly.

In the first year, we will construct a 2-channle head mounded stochastic resonance visual stimulator. The subthreshold white noise LED photic stimulus will be applied to the eyes of the subject. The relationship between perceptive mutual information of the subject and light stimulus intensity will be quantized by measuring the visual evoked potential in the primary visual cortex. The visual perception has close relationship with eye movement. For evaluating the improvement of visual perception due to stochastic resonance visual stimulation, the eye movement signals will be recorded by an eye tracking system when the subject looks at the objects with different resolutions, different profiles, or different velocities. In the second year, the kinect-based motion sensing training games will be developed including maze game, batting ball game, dodge ball game, and soccer game to increase older persons' incentive to exercise sensorimotor integration training and postural-suprapostrual dual task training. The eye movement signals, such as fixation point, fixation duration, number of fixations, fixation sequence, and area of interest will also be measured to assess the visual attention function and visuomotor coordinative ability when the subject plays a motion sensing training game.

Keywords: postural control, stochastic resonance, motion sensing games