

眼动仪在神经康复中的应用现状及研究进展

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摘要 眼动仪作为一种简便可靠、能实时追踪并分析受试者眼球移动情况的设备,已广泛应用于心理学、眼科学等领域的研究,同时也给临床诊疗发展带来了新契机。目前,眼动仪在神经康复中的应用尚处于起步阶段,本文旨在对其应用现状及研究进展进行综述,为神经康复策略的探索提供新思路、新方法。

关键词 眼动仪; 眼球追踪技术; 神经康复; 康复治疗; 康复教育

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Present status and progress of eye-tracker in neurological rehabilitation

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Abstract As a simple and reliable device that can help to record and analyze real-time eye movement, eye tracker has been widely used in psychology and ophthalmology. It has also brought new opportunities to the development of clinical diagnosis and treatment. At present, the application of eye tracker in neurological rehabilitation is still in its infancy. This paper aims to provide new ideas and methods for neurological rehabilitation by analyzing the current status and progress of eye-tracker in neurological rehabilitation.

Key words Eye-tracker; Eye-tracking technology; Neurological rehabilitation; Rehabilitation therapy; Rehabilitation education

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在现实环境中,至少 80% 的外界信息通过视觉获得,大脑皮层中 60% 以上区域与视觉认知功能有关^[1]。眼睛的运动与调整,即眼动,反映了大脑对视觉信息的处理与加工规律^[2]。因此,眼动信号分析是人类认知研究中最普遍的研究手段之一。眼动仪是一种可以精确定位眼球位置、追踪眼球运动情况及分析视觉信号的仪器^[3]。其原理主要是通过人眼视觉捕捉系统实时运动摄像头,通过眼动分析仪器测量眼球的注视点位移和眼-头位移的相对变化值来记录眼球位置以及追踪眼部运动情况^[4],然后通过机器人内置的人工智能进行精确分析。眼动仪一般追踪采集三大典型眼动行为——注视(Fixation)、扫视(Saccade)和瞳孔尺寸(Pupil size)^[5],其具体参数包括行为类型、持续时间、注视位置坐标、扫视角度、瞳孔尺寸、瞳孔检测有效性等^[6]。眼动仪收集的数据可生成眼动轨迹图和热点图^[7],用以形象生动地描述受试者眼动轨迹、部分凝视点和感兴趣区域的视觉关注情况^[8]。因此,眼动仪可以协助我们实时追踪并分析受试者眼球移动情况,已广泛应用于心理学、眼科学等学科的研究中,但在神经康复中的应用尚处于起步阶段。本文旨在对眼动仪在神经康复临床、人才培养中的应用现状及研究进展进行综述,为广大医务工作者、医工交叉研究者提供参考。

1 眼动仪在医学中的应用

眼动仪是心理学基础研究的重要仪器,在医学领域也有着较为广泛的应用^[9]。研究表明,医生的视觉感知信息与临床决策过程息息相关^[10]。Mohamad S M 等^[11]使用眼动机器记录了眼科医生和验光师在诊断眼底照片时的眼球运动,结果发现眼科医生的扫描路径更简单,扫视范围

更大,主要集中在照片的中间区域;而验光师的扫描路径较宽,扫视范围较短,扫视面覆盖较宽的眼底区域,且集中在一些不相关的眼底区域。两组之间的诊断效率和视觉搜索模式截然不同,这也揭示了为什么眼科医师与验光师会对同一近视病人给出不同的治疗方案。YANG H 等^[12]研究表明,眼动仪不仅可以定量评估术前和术后眼球震颤情况,还可用于分析手术对眼球运动的改善效果。也有研究发现,瞳孔直径可以用来描述外科医生的工作负荷水平^[13]。此外,GE F F 等^[14]发现 VR 眼动仪在实验室条件下获得的平均瞳孔直径、0 平均注视时间和注视点可用于检测谎言。更有趣的是,营养师利用眼动追踪系统研究了人们在无意识状态下对食物的喜好,为更好地制定个性化、合理化的营养学方案提供了客观、量化的指标^[15]。同时,美容整形领域也将眼动分析用作确定整形方案的工具之一^[16]。

2 眼动仪在神经康复临床中的应用

2.1 儿童自闭症

自闭症是一种由遗传和环境因素共同作用导致的复杂疾病^[17],其临床特征是社交沟通困难及异常的重复性行为。患者往往具有非典型的认知特征,例如社交认知受损、执行功能障碍及非典型的感知和信息处理能力等^[18]。

眼动仪可作为检测和治疗自闭症患者的有效临床仪器^[19],对自闭症患者的眼动数据分析发现,自闭症患儿对社会刺激的关注明显减少,也难以处理面部和声音信息之间的联动方式^[20]。研究表明,眼动仪可以明显提高视觉在自闭症诊断中所占权重,利于自闭症的早期筛查^[21],而眼动仪中内置的机器学习的相关算法也可协助降低检测成本、实现自闭症患者的标准化诊断^[22]。在自闭症患者的治疗方面,学者们运用

眼动仪与电描绘眼球追踪算法来训练患者，结果发现患儿的注意力定向障碍、眼球运动的速度和准确性明显改善，自闭症患者的社交能力明显提高^[23]。同时，医生也可使用眼动仪独特的实时视觉反馈功能与基于探头的追踪功能对自闭症患者进行治疗^[24]。此外，眼动仪还可用于自闭症儿童的康复教育^[25]。

2.2 中枢神经损伤

眼动仪在中枢神经损伤中的应用主要集中在诊断、预后分析和功能康复方面。Cifu D X等^[26]人使用头戴式眼动分析仪器对患者的眼动模式、眼球运动速度和瞳孔开放度进行监测，并结合其他颅脑损伤的体征，实现对轻度颅脑损伤患者的量化诊断。此外，有学者运用眼动仪和配套的运动分析系统研究脊髓损伤患者本体感受器受损情况从而制定治疗方案^[27]。在神经损伤的预后判断方面，医生对中重度颅脑外伤病人给予一定刺激后，观察其眼动数据来判断其生存概率^[28]。在神经康复治疗方面，学者们运用眼动仪对重度颅脑外伤患者进行视觉方面的康复锻炼，促进了认知功能和其他大脑功能区的复健，并且患者的语言能力也得到较大幅度提升^[29]。也有学者将眼动仪应用于闭锁综合征患者的康复中^[30]，通过使用带有实时反馈光标的眼动仪，引导患者的眼球随光标运动而运动，从而刺激大脑相关脑区的功能恢复。

2.3 神经退行性疾病

神经退行性疾病由大脑和脊髓的细胞神经元损害所致^[31]，其病情会随着时间的推移逐步恶化，严重时会导致大脑功能障碍^[32]。目前，眼动仪已被广泛应用于神经退行性疾病的康复诊疗过程中^[33]。研究表明，眼动仪、眼电图和脑机接口一同被作为肌萎缩性侧索硬化患者与外界交流的措施之一^[34-35]，其便利性及患者依

从性比较令人满意。眼动仪在阿尔茨海默症的早期筛查研究中也有着显著优势，它可通过自带的三维立体的视觉感官系统评估患者的认知障碍程度，还可凭借执行心理旋转任务时患者的眼动数据分析来筛查其空间能力损害状况^[36]。此外，眼动仪或头戴式眼动仪也被用于监测多发性硬化患者的眼睛扫视状况，从而辅助多发性神经退化的诊断^[37]。有学者将眼动仪作为神经退行性疾病中前庭眼反射抑制的评估手段，并结合步态分析，为患者制定个性化的康复方案^[38]。研究发现，帕金森患者的眼部震颤并不源于头部的震颤运动，这在一定程度上为解释该疾病的成因带来了突破性进展^[39]。因此，眼动仪不仅有助于神经退行性疾病患者与外界的交流，也有助于评估患者的认知障碍及视觉加工信号损害情况。

2.4 脑瘫

脑瘫主要表现为中枢性运动障碍及姿势异常，还可伴智力低下、癫痫、感知觉障碍、语言障碍及精神行为异常^[40]。眼动仪可以用于脑瘫的早期诊断，其方法主要是通过监测受试儿童目光到达目标物体的时间来判断其罹患脑瘫的可能性^[41]。此外，眼动仪也被用于脑瘫患儿的治疗及疗效评估。学者们检测儿童康复治疗如格斗训练中患儿的眼球反应能力，了解其对认知功能的治疗效果^[42]，同时，眼动仪可用于帮助脑瘫儿童与外界的交流，且长时间使用后患儿的疲劳报告率较低^[43]，但高昂的价格限制了其进一步推广应用^[44]。

2.5 其他疾病

眼动仪在检测重症肌无力、脑卒中后认知功能障碍、周围神经损伤中也起着一定作用。研究者应用眼动仪对受试者向上凝视时表现出的眼睑固定不稳状况进行捕捉，从而精确识别

重症肌无力患者的疲劳特性,为早期临床诊断提供量化指标^[45]。Singh T等^[46]运用集合了眼动仪的上肢康复机器人来检查健康成年人和中风幸存者在认知功能评估——连线试验中的视觉搜索特点,结果发现脑卒中患者在测试过程中缺乏整合空间规划和工作记忆的能力。此外,Oguntosin V等^[47]通过定位和跟踪周围神经损伤患者在图形用户界面上的眼球运动,对康复机器人进行控制,从而实现对受累肢体的康复训练。

3 眼动仪在神经康复人才培养中的应用

眼球追踪技术已经被广泛应用于定量描述人的认知过程、认知负荷、区分判断错误来源等方面的研究,这项技术也是创建靶向训练程序的关键所在^[48]。在对神经康复人才培养过程中,学者们运用剪辑的患者步态视频,分别对初学者和较有经验的康复治疗师进行步态分析时的观察点和凝视时间进行记录,从而得出其视觉搜索策略,并运用该视觉搜索策略对初学者进行训练^[49]。无独有偶,在康复器具的操作上,学者们利用眼动仪来辅助检测使用者的眼动轨迹,分析操作者学习认知过程,从而更高效的设计学习任务^[50]。因此,眼动仪在康复人才培养中具有广阔的应用前景,值得进一步推广^[51]。

4 总结与展望

随着技术改革的不断深化,康复诊疗的客观化、精准化需求日益增加^[52]。尽管眼动仪在国内康复科实践中的应用仍处于起步阶段,却具有广阔的临床及科研应用前景。目前,眼动仪在自闭症的早期筛查、早期干预与治疗中的应用在国外已较为成熟,但在国内仍处于萌芽

状态。随着医工结合、康工结合的不断发展,眼动仪将越来越多的与机器人技术、虚拟现实技术、5G技术等高新技术结合,在康复乃至整个医学领域展示出它独有的魅力^[53]。

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