

# 可穿戴设备在痴呆患者早期诊断中的应用进展

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## 摘要

痴呆是以认知功能减退为核心的临床综合征, 由于目前尚缺乏能够延缓疾病进展的治疗方法, 早期诊断显得尤为重要。然而, 患者往往在病程后期才就医, 导致早期发现较为困难。可穿戴设备通过监测步态、活动能力等生理行为指标, 为痴呆的早期识别提供了一种客观、动态的评估手段。本文综述可穿戴设备在痴呆早期诊断中的应用效果、风险及挑战, 以期为临床实现早期精准诊断提供参考。

## 关键词

痴呆, 可穿戴设备, 早期诊断, 综述

# Advances in the Application of Wearable Devices in the Early Diagnosis of Dementia Patients

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## Abstract

Dementia is a clinical syndrome characterized by cognitive decline. Due to the current lack of disease-modifying therapies that can slow its progression, early diagnosis is particularly crucial. However, patients often seek medical attention only in the later stages of the disease, making early detection challenging. Wearable devices, by monitoring physiological and behavioral indicators such as gait and physical activity, offer an objective and dynamic means for the early identification of dementia. This article reviews the application efficacy, risks, and challenges of wearable devices in the

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early diagnosis of dementia, aiming to provide a reference for achieving precise early diagnosis in clinical practice.

## Keywords

Dementia, Wearable Devices, Early Diagnosis, Review

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## 1. 引言

痴呆症是一种全球性的流行病,患者常表现为记忆力减退、思维速度下降、精神敏锐度降低,以及语言、理解力、判断力、情绪、运动和日常活动等多方面的功能障碍,给患者家庭及医疗系统带来沉重负担[1]。据统计,目前全球约有5000万痴呆症患者,预计到2050年,这一数字将增至1.52亿[2]。2019年,我国65岁及以上老年人中痴呆症的患病率为5.60%,全球每4名痴呆患者中就有1人为中国人,预计到2050年,我国60岁及以上痴呆患者数量将较2015年翻两番,痴呆症已成为健康中国建设中不可忽视的重大公共卫生问题[3]。近年来,尽管药物治疗领域取得了重要进展,但对痴呆患者的治疗手段仍存在较大局限性,这使得痴呆前期的早期预警与干预对于延缓发病、降低发病率具有重要意义[4]。在此背景下,可穿戴设备正逐步成为痴呆患者早期诊断的重要工具,为其提供了关键的数据支撑。本文拟围绕可穿戴设备在痴呆早期诊断中的应用效果及面临的风险挑战进行综述,以期为我国痴呆患者的早期诊断提供参考[5]。

## 2. 可穿戴设备概述

20世纪60年代,可穿戴技术的概念最早由美国麻省理工学院媒体实验室提出[6]。自此,该领域逐渐引起全球研究者的广泛关注。近年来,可穿戴技术在医疗健康领域发展尤为迅速,出现了便携式医疗或健康电子设备等形式,可用于健康监测甚至疾病治疗[7]。可穿戴设备主要具备以下五个特征:1)无线移动性;2)交互性与智能化;3)可持续性与持久性;4)操作简便、小型化;5)可穿戴性与便携性,其运行与应用依赖于多种关键技术,包括传感器技术、医疗芯片技术、无线通信技术、电源管理技术、显示技术及信息反馈技术等[8]。设备采集的实时医疗数据可传输至互联网,供医疗专业人员进一步分析或提供反馈[9]。目前,可穿戴设备正越来越多地应用于痴呆患者的早期诊断。随着相关技术的不断成熟,痴呆患者将更显著地感受到其带来的便利[10]。

## 3. 可穿戴设备在痴呆患者早期诊断中的应用效果

痴呆患者通常表现为认知能力的逐渐下降,这种变化会反映在步态、语言等日常活动中[11]。目前,量化认知衰退的主要方法依赖于专家通过一系列认知测试进行评估,该方法存在一定局限性[12]。而借助可穿戴传感器,在日常活动中持续监测患者的生理与行为状态,则有助于更早地发现痴呆迹象,这表明,可穿戴设备在痴呆患者的早期诊断中具有重要价值[13]。

### 3.1. 睡眠监测

可穿戴设备用于分析早期痴呆患者的睡眠模式,通过监测睡眠情况评估患者是否存在认知损伤[14]。

Geng 等[15]提出一种结合可穿戴设备与无线脑电图(EEG)耳机的监测方法, 提取 40 名参与者的睡眠慢波与纺锤体特征, 并在门控循环单元(GRU)网络中实现了 93.46% 的分类准确率。该研究显示, 睡眠 EEG 信号在早期痴呆检测中的表现优于清醒 EEG 信号, 进一步支持睡眠慢波与纺锤体特征可作为痴呆早期生物标志物的潜力。由此, 基于可穿戴设备的生理数据为早期痴呆的临床识别提供了新的可能性[16]。然而, 当前研究虽在特定样本中取得了良好分类效果, 但缺乏对不同研究结果之间异同与矛盾之处的系统分析[17]。例如, 关于睡眠 EEG 特征在早期痴呆识别中的诊断效能, 不同研究在特征选择(如慢波与纺锤体的定义参数)、样本来源(如认知障碍亚型、病程阶段)、设备配置(如 EEG 电极位置、采样率)及分类模型等方面存在较大差异, 导致结果之间难以直接比较[18]。部分研究强调睡眠慢波密度下降与认知损伤的关联, 另一些则认为纺锤体密度或振荡耦合的异常更具诊断价值, 相关结论尚未形成统一共识[19]。此外, 现有研究多为小样本、单中心探索性分析, 缺乏对诊断效能(如灵敏度、特异度)在不同人群中稳定性的讨论, 亦未充分控制药物使用、共病睡眠障碍等混杂因素对结果的干扰[20]。未来研究需在方法学标准化、样本多样化及多模态数据融合等方面加强, 以更全面地评估基于睡眠监测的早期痴呆识别方法的临床适用性与推广价值[21]。

### 3.2. 步态检测

早期痴呆患者常伴有执行控制功能损害, 尤其是抑制性控制的减退。此类功能缺陷与运动皮层过度兴奋共同影响步态调控[22]。步态作为反映大脑整合运动控制与认知功能的重要行为指标, 其细微变化难以通过临床观察准确捕捉。可穿戴设备凭借轻便、低负荷、可连续采集等特点, 能够在自然生活环境中对步态进行客观量化, 为早期痴呆识别提供了新的技术手段[23][24]。相较于健康老年人, 痴呆患者呈现步速减慢、步幅缩短、步幅时间变异性增大的特点, 且步态参数异常与跌倒风险升高密切相关[25]。Mulas 等[26]利用可穿戴设备分析老年人的步态速度、步幅、步频及双支撑时长, 发现早期痴呆患者在上述指标上均表现异常, 验证了基于可穿戴传感器的步态测量工具在认知障碍筛查中的应用潜力[27]。然而, 当前研究多停留于现象描述层面, 对步态指标诊断效能的认识尚不一致, 部分研究强调步速与步幅的敏感性, 另一些则指出步幅时间变异性或双支撑时长更具区分力[28]。此类差异可能与样本特征、可穿戴设备配置(如传感器佩戴位置、采样频率)及分析方法的不同有关。未来研究需加强方法学标准化, 并结合多模态数据融合, 以充分发挥可穿戴设备在步态分析中的技术优势, 提升其在认知障碍早期筛查中的应用价值[29]。

### 3.3. 语言识别

早期痴呆患者常出现记忆、逻辑、语言及执行功能障碍, 严重时可能影响社交互动[30]。痴呆相关的言语和语言变化可能在临床症状出现前数年即已显现。传统语言评估多依赖人工记录与主观评分, 难以捕捉自然情境下的细微异常。可穿戴设备通过内置麦克风或语音采集模块, 可在日常交流中连续、无干扰地采集语音数据, 为语言功能的客观量化提供了新的技术路径[31]。Balogh 等[32]利用可穿戴设备采集语义流畅性任务中的语音数据, 发现无声停顿次数、无声停顿平均时长及平均单词转换时间对早期痴呆检测更具价值。Wang 等[33]基于可穿戴设备采集 75 名参与者在图片描述与自发自我介绍中的语音样本, 对词汇、语义、句法、语音流利度及声学特征进行多维度分析。研究[34]表明, 早期痴呆患者典型表现为语音产出减少、不流畅度增加, 以及语义内容与句法复杂性下降。上述研究验证了基于可穿戴设备的语言分析在痴呆早期识别中的应用潜力。然而, 当前研究多停留于现象描述层面, 缺乏对不同研究结果的深入剖析。两类研究在语言任务类型、特征提取方式、可穿戴设备采集配置(如采样率、麦克风位置)及分析维度上存在较大差异, 结论难以直接比较[35]。此外, 现有研究多为小样本探索性分析, 对教育水平、语言背景等混杂因素控制不足。未来研究应加强方法学标准化, 注重多中心、大样本验证, 以充分发挥

可穿戴设备在语言分析中的技术优势, 提升其在早期痴呆识别中的临床适用性[36]。

## 4. 可穿戴设备在痴呆患者早期诊断中存在的问题

尽管可穿戴设备在痴呆患者早期诊断领域展现出广阔的应用前景, 但其在临床推广与规模化应用中仍面临诸多挑战, 主要体现在行业标准、技术性能及数据安全等方面[37]。

### 4.1. 缺乏行业标准和法规

当前, 可穿戴设备市场处于快速发展但缺乏统一规范的状态。各设备制造商多依据自身技术路线和核心产品构建独立的数据采集与处理体系, 导致设备间数据格式、通信协议、分析指标各异, 难以实现跨平台数据整合与互认[38]。这种局面不仅阻碍了多源数据的融合利用, 也使得不同研究结果之间的横向比较困难, 限制了临床证据的积累与转化[39]。因此, 亟需建立和完善针对医疗级可穿戴设备的行业标准与监管法规, 明确设备性能指标、数据接口规范及临床应用准入门槛, 为技术的规范化发展提供制度保障[40]。

### 4.2. 技术壁垒

尽管可穿戴设备在痴呆早期诊断中展现出良好的应用效果, 但其核心技术仍存在若干瓶颈, 制约着临床应用的可靠性与广泛性[41]: 1) 数据准确性与特异性不足。当前可穿戴设备所采用的传感器在捕捉认知相关生理与行为特征时, 其灵敏度和特异性尚不理想, 易受环境噪声、个体差异等因素干扰, 可能导致特征提取偏差, 进而增加误诊、漏诊及不必要的后续检查风险。2) 功能集成度低。多数可穿戴设备功能较为单一, 难以实现对睡眠、步态、语言等多维度指标的同步采集与综合评估。兼容性差的问题也使得设备难以与医院信息系统或其他医疗设备有效对接, 阻碍了多模态数据融合分析的实现。3) 电池续航能力有限。为实现轻便舒适的佩戴体验, 可穿戴设备在体积和重量上受到严格限制, 这直接制约了电池容量。如何在低功耗条件下实现长时间连续监测, 同时保证数据处理与传输的稳定性, 仍是当前设备研发中亟待攻克的技术难题[42]。

### 4.3. 数据存在隐私泄露风险

随着机器学习与人工智能技术的深度应用, 可穿戴设备能够持续采集用户的生理参数、行为轨迹、语言内容等高维度的个人敏感信息[43]。这些数据具有格式多样、体量庞大、传输链路复杂等特点, 在采集、存储、传输、分析各环节均面临潜在的隐私泄露风险, 若缺乏完善的数据安全管理机制, 不仅可能侵害患者个人隐私, 还可能削弱公众对新兴技术的信任度, 进而影响可穿戴设备在临床中的推广与接受[44]。因此, 亟需制定覆盖数据全生命周期的安全管理策略, 在保障数据效用与维护个人隐私之间寻求平衡。

## 5. 可穿戴设备在痴呆患者早期诊断中的应用展望

面向未来, 随着技术迭代与临床需求的深度融合, 可穿戴设备在痴呆早期诊断领域的发展将呈现多元化、智能化、人性化的趋势[45]。

### 5.1. 统一行业标准

建立统一、开放的行业标准是推动可穿戴设备从分散走向融合的关键。未来应以健康护理为核心应用场景, 构建涵盖数据采集、特征提取、结果解释的全流程标准化体系[46]。具体而言, 需统一数据分类标准、评价指标体系及接口协议, 确保不同品牌、不同型号设备所生成的数据能够在临床层面实现互认

与共享, 标准的确立不仅有助于提升研究结果的可靠性与可比性, 也为大规模临床应用提供了技术基础[47]。

## 5.2. 患者依从性

可穿戴设备的临床价值高度依赖于患者的长期佩戴与持续使用。因此, 提升患者依从性是设备设计与应用中需重点关注的环节。在佩戴形式上, 患者更倾向于选择简便、隐蔽的设备, 如上臂佩戴式相较于手腕佩戴式更不易被察觉, 有助于减轻在公共场合佩戴时的尴尬感与病耻感[48]。在功能设计上, 应向患者提供更为全面的服务, 如实时数据分析与反馈、用药提醒、防水设计、康复指导等, 以增强设备的实用性与使用黏性[49]。此外, 通过简洁直观的用户界面与人性化交互设计, 可进一步降低老年人群的使用门槛。

## 5.3. 新材料的应用

柔性电子材料的出现为可穿戴设备的发展带来了革命性变化[50]。此类材料能够模拟人体皮肤的柔软度与弹性, 具备柔韧性、轻量化、高适配性等优异特性, 为设备形态的创新设计提供了广阔空间[51]。在医疗健康领域, 柔性电子材料已逐步应用于智能服装、连续健康监测、辅助生活等方向[52]。展望未来, 随着柔性材料制造工艺的不断成熟与性能的持续优化, 将催生出更具功能性与实用性的可穿戴设备, 为痴呆患者的早期诊断提供更加个性化、舒适便捷的健康管理体验[53]。

## 5.4. 保护数据隐私和安全

数据隐私与安全保护是可穿戴设备在医疗领域可持续发展的根本保障。未来需投入充足资源, 构建贯穿数据采集、传输、存储、分析全过程的隐私保护机制[54]。在管理层面, 应制定明确的数据安全规则, 对数据的访问权限实施严格控制, 确保敏感信息不被滥用或泄露。在制度层面, 应要求设备制造商严格遵循隐私保护法规, 明确医疗机构、设备厂商及患者在数据使用过程中的权责关系[55]。在用户授权方面, 应赋予痴呆患者或家属对数据使用的知情权与决定权, 允许其在匿名化前提下共享数据, 并确保其对数据用途的充分知情[56]。通过技术与管理双管齐下, 逐步建立起公众对可穿戴医疗设备的信任基础。

## 6. 小结

本文系统梳理了可穿戴设备在睡眠、步态、语言等维度的持续监测能力及其在痴呆早期诊断中的应用进展。现有研究已初步验证单一模态行为特征与认知障碍的关联性, 表明可穿戴设备在社区化筛查场景中具备潜在应用价值[57]。然而, 当前研究仍面临标准化缺失、设备配置与特征定义不统一等问题, 且多聚焦于单模态特征的孤立分析, 因任务范式、设备类型及特征提取方式不同, 难以实现结果的有效整合与横向比较, 制约了临床转化进程[58]。基于上述进展与瓶颈, 未来研究应从单模态分析转向多模态数据融合的痴呆早期诊断模型构建, 即可穿戴设备同步采集多维度数据, 通过特征级或决策级融合策略建立个体化预警模型[59]。随着柔性电子技术与隐私保护算法的突破, 可穿戴设备有望实现多模态融合的主动智能监测, 为痴呆的社区化筛查与个体化干预提供可行路径。后续需在方法学标准化与临床验证体系建设方面持续发力, 推动可穿戴设备从研究工具向临床辅助决策系统转化[60]。

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