健康环境视角下开放式办公空间声环境问题及影响

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摘要 工作场所的环境健康是员工身心健康的基本保证, 其中声环境对员工情绪健康和工作绩效影响显著. 基于开放式办公空间的广泛应用和空间开放性带来的特殊声学问题, 近10年间, 学界持续而深入地展开研究, 取得了丰富的成果. 以Web of ScienceTM核心合集为数据来源, 利用CiteSpace可视化图谱分析工具对国内外的环境与建筑声学、心理声学、职业健康、环境心理学、工效学、人因技术等领域的研究成果进行文献分析, 归纳研究热点, 总结研究发现, 综述开放式办公空间的声环境问题及其对办公人员的健康影响. 研究发现, 开放式办公空间的主要干扰声源是作为背景声存在的无关言语; 言语私密性是开放式办公空间声环境最主要的问题; 语言传输指数STI (speech transmission index)能够很好地表征空间的言语私密性, STI越高, 无关言语的可懂度越高, 产生的干扰就越大. 声环境问题产生的健康影响可以概括为心理干扰和认知干扰两个层面. 前者引发声烦恼, 加强疲劳、压力、烦躁等负面情绪; 后者降低员工的认知绩效, 增加认知负荷. 为保证开放式办公空间声环境的健康和舒适, 应在理论研究、技术探究和管理政策等层面深入推进, 尽快建立适应我国办公场所和汉语言环境特征的评价标准, 作为职业健康管理、办公建筑设计和声环境改造的依据.

关键词 开放式办公空间, 声环境, 言语私密性, 无关言语, 情绪影响, 认知干扰

随着现代城市生活日益高效快捷, 职场人群更易产生心理消耗、工作效率下降、负面情绪滋生等现象^[1], 工作场所的环境健康特别值得关注. 其中, 声环境作为听觉体验要素, 对创造健康、舒适、高效的办公环境, 维护使用者身心健康至关重要. 开放式办公空间内部空间开敞, 易于实现自然通风和采光, 且有利于员工之间的沟通合作和知识共享分区少、建筑成本较低、员工密度高、租金相对较低^[2], 得到越来越广泛的应用. 与此同时, 空间开放性带来的声环境的特殊问题成为研究者关注的焦点.

在职业健康领域, 国际标准《职业健康安全管理体系要求与指南(ISO45001:2018)》提出“健康工作场所”的管理体系^[3], 我国《职业健康监护技术规范(GBZ188-2014)》则对接触有害声环境的作业人员职业健康提出了明确监护^[4]. 相较于车间、建筑施工场地等高噪声暴露的职业场所, 办公空间的声环境相对安静, 不会产生一般意义上的噪声危害. 但是, 健康环境视角下的声环境研究从单纯重视噪声负面影响, 转移到全面考察声环境对人的综合影响, 重视人的听觉感知和体验^[5]. 根据世界卫生组织WHO(World Health Organization)的定义, “健康是一种身体、心理和社会幸福感的完满状态, 而不仅仅是没有疾病或虚弱的状态”.

随着现代城市生活日益高效快捷, 职场人群更易产生心理消耗、工作效率下降、负面情绪滋生等现象^[1], 工作场所的环境健康特别值得关注. 其中, 声环境作为听觉体验要素, 对创造健康、舒适、高效的办公环境, 维护使用者身心健康至关重要. 开放式办公空间内部空间开敞, 易于实现自然通风和采光, 且有利于员工之间的沟通合作和知识共享分区少、建筑成本较低、员工密度高、租金相对较低^[2], 得到越来越广泛的应用. 与此同时, 空间开放性带来的声环境的特殊问题成为研究者关注的焦点.

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Liu Y, Zhang Y, Zhang R N. Problems and impacts associated with the acoustic environment of open-plan offices from the perspective of healthy environment (in Chinese). Chin Sci Bull, 2020, 65: 511–521, doi: [10.1360/TB-2019-0524](https://doi.org/10.1360/TB-2019-0524)

(Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity)^[6]在这样的状态中,个人能够意识到自我能力,能够应付正常的生活压力,能有效工作,能为团队做出贡献^[7].欧洲联盟《健康建筑白皮书(2016)》指出,健康建筑旨在“满足使用者生理、心理和社会需求”^[8];美国针对办公建筑制定的《Well健康建筑标准(2014~2019)》在心理健康视角下“倡导提供有利于认知和情绪健康的物理环境”,而物理环境舒适性评分控制项中,声环境因素占比达到50%(以一级指标计算, <https://resources.wellcertified.com/zh-cn/tools/well-building-standard-v1/>);我国《健康建筑评价标准(T/ASC02-2016)》同样关注了包括声环境在内的物理环境对使用者身心健康的重大意义^[9].可见,健康环境视角下开放式办公空间声环境的研究和审视,应包含对工作人员生理、心理和工作表现等层面的影响.

芬兰、法国、希腊、匈牙利、意大利、荷兰、葡萄牙、西班牙^[10]和中国^[11~13]等地大规模调查显示,声环境质量与办公人员总体舒适度的关系最为显著,其次是空气质量、光环境和热环境.对于长时间处于办公环境的人员,良好的声环境可以令其心理愉悦,注意力提高,反之则会使其产生烦躁和疲惫^[14].开放式办公空间的声环境对办公人员情绪心理和工作绩效影响显著^[15,16],且影响的程度超过封闭办公室^[2,17,18].

近10年,国际领域对于开放式办公空间声环境的研究更为持续和深入,取得了丰富而有价值的研究成果.本文以健康环境为视角,通过对国内外开放式办公空间声环境的前沿研究进行文献分析,归纳研究热点,总结研究发现,综述开放式办公空间的声环境问题及对办公人员的健康影响.

1 基于文献计量的研究热点分析

利用CiteSpace可视化图谱分析工具对开放式办公空间声环境研究的现状进行统计和分析^[19].对开放式办公空间类文献进行界定,采用Web of ScienceTM核心合集,访问Clarivate Analytics引文数据库SCIE, SSCI, A&HCI;国际会议录引文索引CPCI-S, CPCI-SS&H, ESCI, IC, CCR.检索关键词设定为“开放式办公空间”、“噪声或声环境或ISO或幸福感或健康”,英文检索策略: TS=(open plan office* AND (noise* OR acoustic* OR ISO* OR well-being* OR health*)),时间跨度为所有年份.对文献进行主题检索筛选后,获得英

文文献95篇,实际时间跨度为2009年3月~2019年10月.

1.1 文献聚类及拓展分析

针对所获取的95篇文献,基于共被引分析确认10篇基础文献;基于关键词聚类分析(cluster explorer),得到聚类图和时间线,以发现该领域研究基础及前沿知识结构和发展脉络.数据显示,聚类节点95个、连接线234条(nodes=94, edges=234),网络模块化程度(modularity $Q=0.69$)较高,说明聚类结果结构显著(modularity $Q>0.3$),可以用于分析研究热点与前沿^[20].在上述95篇英文文献基础上,手动增加相应时间段与主题高度相关的EI文献库中12篇英文文献及知网数据库中10篇中文文献,对总计117篇中英文文献进行深入阅读分析,总结提炼开放式办公空间声环境的研究热点及趋势(图1).

对所获取的10篇基础文献进行信息提取,包括发表期刊、文献组内共被引频次(co-citation analysis)、总被引频次(Web of Science)、发表年份、作者隶属机构,结果见表1.对应图1中的热点和关联性,可以看出这10篇基础文献在该领域研究中的影响和贡献分布.首先,从发表期刊来看,声学专业期刊4篇(*Acta Acust United Acust/Appl Acoust*各2篇)、人与环境关系期刊3篇(*J Environ Psychol/Ergonomics/Facilities*各1篇)、物理环境期刊2篇(*Indoor Air*)、国际标准1篇(ISO).其次,从研究机构分布来看,基础文献主要来自建筑环境领域、人与环境关系领域等,学科背景主要是建筑环境学、心理学等,成果贡献率最高的是芬兰职业健康研究所室内环境实验室,独立或合作发表基础文献6篇;芬兰图尔库大学心理学系与其合作发表4篇.

1.2 研究热点及趋势

(1) 声环境质量及指标.各地大样本调查普遍发现,作为背景声存在的无关言语(background speech)是最主要的噪声源,研究者通过实验研究,探究无关言语对使用者的影响.言语私密性(speech privacy)被证实是开放式办公空间声环境质量的核心问题,其指标语言传输指数STI(speech transmission index)得到持续探索;而大空间声学性能指标混响时间RT随着研究的深入不再作为该类空间的核心指标.

(2) 测量标准与技术方法.2012年国际标准化组织颁布了开放办公空间声环境测量标准ISO3382-3,我国于2018年利用翻译法制定和颁布了国家标准GB/

图 1 (网络版彩色)文献热点、关联性及时域分析

Figure 1 (Color online) Literature hotspot, relevance, and time domain analysis

表 1 基础文献及信息提取

Table 1 Basic papers and related information

序号	文献名称	发表期刊	共被引	总被引	年份	机构 ^{a)}
1	Determination of acoustical conditions in open-plan offices: Proposal for new measurement method and target values	Acta Acust United Acust	21	43	2009	①
2	Effects of acoustic environment on work in private office rooms and open-plan offices-longitudinal study during relocation	Ergonomics	17	99	2009	①,②
3	Performance effects and subjective disturbance of speech in acoustically different office types-a laboratory experiment	Indoor Air	22	51	2009	②,①
4	Effects of five speech masking sounds on performance and acoustic satisfaction. Implications for open-plan offices	Acta Acust United Acust	15	35	2011	②,①
5	Acoustics measurement of room acoustic parameters Part 3: Open plan offices (ISO3382-3)	ISO	16	- ^{b)}	2012	③
6	Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design	Indoor Air	12	160	2012	④,⑤
7	Workspace satisfaction: The privacy-communication trade-off in open-plan offices	J Environ Psychol	17	144	2013	⑥
8	Cognitive performance during irrelevant speech: Effects of speech intelligibility and office-task characteristics	Appl Acoust	18	37	2013	⑦,①
9	Effects of unattended speech on performance and subjective distraction: The role of acoustic design in open-plan offices	Appl Acoust	17	41	2014	①,②
10	The effects of intelligible irrelevant background speech in offices-cognitive disturbance, annoyance, and solutions	Facilities	14	23	2015	⑧,⑨

a) ① 芬兰职业健康研究所室内环境实验室; ② 芬兰图尔库大学心理学系; ③ 国际标准化组织(瑞士); ④ 丹麦技术大学国际室内环境与能源中心; ⑤ 美国伯克利加州大学建筑环境中心; ⑥ 澳大利亚悉尼大学建筑与规划学院; ⑦ 瑞典耶夫勒大学环境心理学工程与可持续发展学院; ⑧ 德国天主教大学环境与健康心理学系; ⑨ 德国劳恩霍夫建筑物理研究所。b) 国际标准未见公开统计数据

T36075.3. 标准颁布一方面引发了研究者对测量方法的可靠性、操作性的探索, 另一方面通过实测数据和声场模拟技术, 探索空间声学性能及优化。其中, 声掩蔽(sound mask)作为特殊的优化手段, 逐渐被关注。

(3) 声烦恼与情绪心理。情绪心理层面, 研究者以问卷调查和心理量表的形式, 探究办公人员的声烦恼(annoyance)及听觉引起的心理健康问题, 主要以压力、疲劳、自评健康为指标进行规律探究。人因技术

的发展逐渐支持了以生理指标客观表征心理影响的实验方法。

(4) 认知表现的实验研究. 包含认知绩效(cognitive performance)和认知负荷(cognitive workload)两方面内容. 前者影响工作效率, 后者表征脑力消耗和压力. 研究者在专业声学实验室开展认知任务实验, 就声环境相关因素对员工认知表现的影响进行实证研究。

2 开放式办公空间声环境质量及测量方法

基于空间的开放性, 背景噪声和言语私密性成为潜在的声学问题^[16], 学界对此开展了大量调查研究, 并结合数据制定了开放式办公空间声环境质量的测量方法和指标体系。

2.1 背景声水平及主要声源

背景声(background sounds)来自外部环境和内部空间. 外部侵入声有交通声、商业声、施工机械声、自然声等^[21,22]; 室内声源包括人的谈话声、电子信号声(铃声、提示音)、办公设备声(打印机、复印机、电脑)、人的活动声(脚步声、敲击键盘声)、通风系统运行声等^[23,24]. 北京^[25]、香港^[13]等地的调查显示, 开放式办公空间中最令人讨厌的噪声依次是谈话声、电话铃声、办公设备声和室外噪声, 且对办公人员的工作表现都有显著的负面影响. 也有研究表明, 在某种情况下, 敲击键盘和点击鼠标的声音能够烘托气氛, 提高工作积极性^[26]. 对美国、芬兰、加拿大和澳大利亚92栋外窗可开启的开放式办公建筑进行大样本调查, 结果显示, 室内噪声比室外噪声影响更为显著^[21]. 另有研究证明, 与复印机、电话铃声等其他类型室内噪声相比, 无关语言更具干扰性^[27~29].

Kaarlela-Tuomaala等人^[2]采用纵向调查法进行声学测量和主观评价, 对比搬迁至开放式办公空间前后的声环境状况. 结果显示, 整个工作日的背景噪声水平均值没有显著差异, 但声环境的负面影响增加. 随后, 研究注意到, 声烦恼与员工主观声音强度评价显著相关, 仅依据A计权背景噪声水平 L_{Aeq} 不能很好地评价空间内声环境状况^[29,30].

2.2 言语私密性及语言传输指数STI

言语私密性用于描述空间内临近工位的无关语言入侵的主观感受, 即谈话者的谈话内容不想让其他工位的同事听到, 其他工位的同事也不希望被这个声音

干扰的现象^[31]. 瑞典^[32]、芬兰^[33]、德国^[34,35]、法国^[29]、韩国^[36]、中国^[14,37]等地调查显示, 在开放式办公空间中, 言语私密性是声环境最主要问题。

为了更好地探究和解决开放式办公空间的声环境问题, 确定参量以定量描述空间声学性能至关重要. 对于开放式办公空间, 早期延用混响时间RT作为评价参数. 混响时间是指在室内声音已达稳定状态后, 中断声源的发声, 平均声能密度自原始值衰变到其百万分之一所需要的时间^[38]. 但研究者逐渐意识到, 混响时间不能很好地预测整个空间的声音衰减状况, 自2011年不再作为该类空间的核心指标。

针对言语私密性, 研究者先后探索了清晰度指数AI(articulation index)、语言传输指数STI、快速语言传输指数RASTI(rapid speech transmission index)、语言可懂度指数SII(speech intelligibility index)^[31,39,40]等参量的科学性与可行性. 其中, 语言传输指数STI是与可懂度相关的表征语音传输品质的物理量, 其数值区间为(0,1), 表征言语从完全听不见到完全听懂的程度区间^[41]. 研究证实, 这个指标与员工认知能力及听觉舒适性显著相关, 能够更好地描述空间某点的言语私密性^[42].

2.3 测量方法与标准

在言语私密性的测量和评价方法上, 早前通过确定两个相邻工位之间的语音清晰度, 客观估计干扰和言语私密性. 考虑到声干扰并不只来源于最近的工位, Virjonen等人^[43]提出“言语影响预测法”来测量和表征整个办公空间的状况, 确定了3个单值评价量: 言语声空间衰减率 $D_{2,S}$ 、声源4 m处A声级 $L_{p,A,S,4m}$ 、分心距离 r_D . 随后, ISO国际标准化组织颁布《开放式办公室声环境测量标准(ISO3382-3:2012)》, 采用和规范了该测量方法^[41], 并增加两个参考评价量: 最近工位处STI、私密距离 r_p . 其中, 分心距离 r_D 和私密距离 r_p 均是利用STI随距离变化的线性回归进行预测确定. 此后, Yadav等人^[44]针对ISO3382-3标准声学参量的可重复性和可靠性进行了探索, 进一步明确了声环境测量路径的确定方法。

国内学者康升娴和欧达毅^[45]于2016年详细介绍了该标准所采用的言语私密性测量和评价方法, 并提出应针对我国具体情况进行技术方法的适用性探索. 2017年, 依据该标准对国内5个开放式办公空间进行了综合测评, 对声环境质量与测量参数之间的关系进行了分析与讨论, 证实声环境测评需多参数综合考虑, 实

践总结了测评的一般流程和注意事项^[37]。2018年,我国利用翻译法颁布国标《GB/T36075.3-2018声学室内声学参数测量第3部分:开放式办公室》^[46],等同于完全采用ISO3382-3国际标准,没有做适应性调整。

3 声环境对工作人员情绪及心理的影响

学界针对开放式办公空间声环境对员工健康的影响主要以调查研究的方式进行,根据研究对象及研究问题,主要调查方法包括:大样本描述性调查(descriptive survey)、分组横断面调查(cross-sectional survey)、搬迁前后纵向调查(longitudinal survey during relocation)。调查中使用声满意度量表Acoustic S^[28](acoustic satisfaction)、声烦恼量表GABO^[29](French acronym for acoustic annoyance in open-plan offices)、自评健康量表SATIN^[47]、自评疲劳量表SOFI^[48](Swedish occupational fatigue inventory)等测量员工的声环境体验和情绪心理,证实声环境问题可能导致员工产生声烦恼,引发不良的精神状态或心理。

3.1 声烦恼

根据欧盟委员会(European Commission)的定义,声烦恼(annoyance)是描述与噪声有关的负面情绪的术语^[49],如厌烦、不愉快、不舒适、心烦意乱的情绪体验^[50]。

首先,声烦恼受噪声源类型及声压级水平的影响。愉快的声景元素能够明显缓解声烦恼的程度^[51],而通风系统、交通等机械噪声则会加剧烦恼^[52];侵入交通噪声的声压级水平越高,被试者烦恼度越高^[53];背景语言声的峰值($L_{AF,10\%}$)与谷值($L_{AF,90\%}$)之间的差值越大,烦恼程度越高^[54]。其次,声环境满意度受噪声暴露时间和工作类型的影响。中国和韩国跨国研究表明,长时间接触噪声会导致环境满意度下降^[36];针对工作类型的对比研究,研究型办公室员工声环境满意度明显低于行政型^[12]。另外,声舒适受言语私密性和声掩蔽效果影响,听觉舒适度随着无关言语可懂度的增加而减弱^[55-57]。

3.2 精神健康

基于主观调查的研究发现,开放式办公空间声环境质量与办公人员的精神健康、疲劳、压力状况相关,噪声干扰显著影响受访者的自评健康^[36]。

Seddigh等人^[32]在同一办公楼内不同声学状况的

空间内进行对比研究,结果表明,空间声学条件与自我认知压力显著相关。Blasio等人^[58]利用描述性调查,证实开放式办公空间中的无关言语引发了烦恼,降低了工作表现,并影响了员工的精神健康和幸福感。瑞典耶夫勒大学运用“疲劳自评量表SOFI”,证实高噪声状况下,参与者自我报告疲劳程度加大,且工作动机下降^[59],听力受损的被试者比正常听力被试者更容易受到高噪声影响,且在高噪声环境下更容易感到疲劳^[60]。

3.3 生理表征

有研究关注声环境对自主神经系统的影响,以生理指标客观表征声环境对办公人员心理压力的影响。Motlagh^[61]与耶夫勒大学^[60]的研究结论一致表明,随着工作人员噪声水平和暴露时间的增加,皮肤导电性SCL和呼吸频率RR也随之增加,即工作人员的心理压力也随之增加。Ma等人^[62]在模拟的开放式办公室中进行实验研究,以血压SP和心率HR变化指标证实,令人愉悦的声景元素对被试者具有心理恢复的作用。

4 无关言语对工作人员认知表现的影响

早期研究表明,在不同噪声源类型中,无关言语(background speech)对工作人员的认知表现影响最为显著^[23,63-65],对被试心理负荷具有显著影响^[66]。近10年间,研究者利用心理学实验的方法和技术,深入探究相关因素对办公人员认知绩效的影响,并逐渐加深对认知负荷的研究。

实验研究在专业声学实验室内进行,以研究关注的声学因素作为控制变量,被试者按照实验设计执行认知任务,以任务得分和心理量表的数据作为因变量指标。Fleishman^[67]引入能力需求法,即以某些任务的最大绩效表现需要的认知能力为依据,利用任务绩效进行评估声环境产生的认知干扰。根据工作类型及对应的认知能力,可选择的任务及范式包括:短时记忆(数字回忆、数字广度digit span-DS_M)、长时记忆(单词流畅性任务)、语义记忆(阅读理解、校对、心算)、推理能力(语法推理grammatical reasoning-GR_R、双重选择double trouble-DT_R)、注意力(旋转rotations(Rot_C) test、特性匹配feature match-FM_C)、计划能力(房树人测验hampshire tree task-HT_P、空间滑块spatial slider-SS_P)等。实验研究结合标准量表进行心理测试,普遍采用的量表包括:自评绩效量表MBI-GS^[68](Maslach burn-out inventory-general survey)、认知负荷量表NASA-

TLA^[69](task load index)、认知压力量表COPSOQ^[70](copenhagen psychosocial questionnaire)、噪声敏感性量表WNS^[71](Weinstein noise sensitivity scale)等。

4.1 无关言语效应与STI-工效预测模型

无关言语效应ISE(irrelevant sound effect)是指, 无关的背景语音显著破坏正在进行的认知任务表现的现象^[72]。中国^[13]、法国^[29]、意大利^[58]等地调查一致表明, 无关言语是开放式办公空间最主要的干扰源。

语言传输指数STI描述的语言可懂度越高, 被试者认知绩效越差, 认知负荷显著增加^[23,73]。芬兰职业健康研究所所长长期关注语言传输指数STI对认知表现的影响, 根据既有文献报告的实验数据, 通过回归建立了最初的“STI-工效预测模型(Hongisto's model, 2005)”^[64]。模型显示, 在STI=(0.2~0.6)的区间内, 被试认知表现呈现明显下降趋势。该模型于2012年被国际标准ISO3382-3所采用, 作为分心距离 R_D (STI=0.5)和私密距离 R_P (STI=0.2)的确定依据。后续研究发现, 认知任务^[74]以及语种^[75]不同, 曲线的形状和性能下降的幅度有所不同。

此外, 研究还关注了无关言语的声压级特性和时间特性。Renz等人^[54]研究发现, 以言语声为主的背景声条件下, 声压级峰值($L_{AF,10\%}$)与谷值之间($L_{AF,90\%}$)的差异越大, 对记忆性能的影响越大。Liebl等人^[76]研究发现, 间歇性言语声比连续言语声对认知绩效的影响更大。

4.2 掩蔽效应与掩蔽声

掩蔽效应(masking effects)是“一种声音的听觉感受被另一种声音影响的现象”^[31]。斯图加特大学声学与建筑物理研究所从2018年开始探索声掩蔽作用对认知表现的影响。研究发现, 稳态掩蔽声(steady-state sound)、反向语音掩蔽声(time-reversed speech)、杂音掩蔽声(babble masking)均能提高空间的言语私密性, 减少无关言语对认知绩效的影响, 但没有证据显示, 反向语音掩蔽声或杂波掩蔽声比稳态掩蔽声更有效^[77]。研究还发现, 当掩蔽声的位置和语音信号从不同方向呈现时, 空间分离导致掩蔽效果下降^[78,79]。另外, 针对声掩蔽措施的舒适性研究表明, 即使掩蔽措施增加了空间的言语私密性, 也不一定会增加听觉舒适度^[80], 声舒适还与掩蔽声类型^[77]、位置及信噪比(signal-noise ratio)等因素有关^[78,81]。

悉尼大学研究者特别关注了多人言语现象产生的杂音掩蔽效应(babble effects), 即办公室里有多人交谈

的情况下, 因互相掩蔽而造成的无关言语清晰度下降的现象^[82]。但同时, 也有可能因此产生较高的声压级水平而产生负面作用, 实验研究并未得出一致的有参考价值的结论^[83~85]。

4.3 工作类型、语种及个体差异

Lee^[86]证实声环境影响下, 不同类型的办公空间使用者在自我报告工作绩效方面存在差异, 开放式办公空间内工作人员的自评绩效更低。Kang等人^[87]对工作类型的影响差异进行探索, 发现认知要求高的工作更容易被噪声干扰, 与行政型工作人员相比, 声环境质量对研究型工作人员的绩效影响更为显著^[12]。瑞典^[32]和芬兰^[88]的研究共同表明, 受干扰程度与室内声学状况相关, 如空间内吸声状况越差干扰越明显。

对比不同语言条件下相同任务(短时记忆)的实验研究发现, 尽管认知绩效随STI升高而降低的曲线趋势基本一致, 但是获得实证的产生干扰的最小STI值不尽相同, 如芬兰语0.35(序列回忆, 37名被试, 变量水平STI=0.1/0.35/0.65)^[55]、瑞典语0.23(单词回忆, 47名被试, 变量水平STI=0/0.08/0.16/0.23/0.34/0.71)^[74]、法语0.4(序列回忆, 57名被试, 变量水平STI=0/0.3/0.4/0.5/0.7)^[89]、德语0.45^[76](序列回忆, 24名被试, 变量水平STI=0.37/0.45/0.53/0.80)/0.2^[90](序列回忆, 19名被试, 变量水平STI=0.2/0.3/0.39/0.48/0.57)。汉语0.32^[91](序列回忆, 变量水平STI=0/0.32/0.5/0.67), 大多高于Hongisto's模型中的0.2。分析其原因, 除了实验范式、实验控制的差异之外, 实验选取变量水平(STI值)的差异也是重要原因。未见相同实验条件下语种间差异对比的研究结果。

研究者还关注了性别、性格、敏感性、听力水平、集中注意力的能力等个体差异的影响, 发现女性^[56]、内向型^[92]、噪声敏感性^[11,36,88]员工更容易受到噪声干扰。

5 展望与建议

基于文献研究, 开放式办公空间的主要干扰声源是作为背景声存在的交谈声, 即无关言语; 言语私密性是开放式办公空间声环境最主要的问题。语言传输指数STI能够很好地表征空间的言语私密性: STI越高, 无关言语的可懂度越高, 产生的干扰就越大。声环境问题产生的不利影响包括心理干扰和认知干扰两个层面, 均对员工心理健康产生不利影响。前者带来声烦恼, 加

强疲劳、压力、烦躁等负面情绪；后者降低认知绩效、增加认知负荷。工作人员的声环境体验及产生的健康影响，与空间类型、工作类型、语种和个体差异相关，但结论尚不充分。

为保证开放式办公空间声环境的健康和舒适，应在理论研究、技术探究和管理等层面进行深入推进，应尽快建立适应我国办公场所和汉语言环境特征的评价标准，作为职业健康管理、办公建筑设计和声环境改造的依据。

(1) 开放式办公空间声学性能测量的国际标准ISO3382-3:2012和国家标准GB/T36075.3-2018规定了该类空间声学性能的测量方法，其测量结果可以用于评价空间的声学性能，但是目前尚无评价标准。标准附录给出的评价参考值来自对两篇英文文献(2009^[43]/2011^[93]年)中21个国外案例的实测结果，而开放式办公空间在空间规模、平面布局、家具布置等方面各不相同，据此得到的评价参考值显然依据不足。我国这方面可见成果数据非常有限，需要进行较大规模的现场实测，根据实测结果建立数据库，以统计数据形成具有实际意义的可操作的评价标准。

(2) 上述测量标准所采用的STI-工效预测模型建立于2005年，该模型系基于1974~2005年的22篇文献所报告的38项相关实验数据，经数学回归得到^[64]。包括创立者团队在内的各国研究者针对不同的认知任务，在不同的语种条件下，对不同的个体进行了实验研究，尽管趋势基本一致，但数值存在差异。针对这种状况，国际

学界积极开展相应研究，努力尝试优化和细化这个模型。由于声环境体验与个体差异显著相关，汉藏语系和印欧语系在语言学和语音学上的差异也决定了STI(基于印欧语系确定)对汉语语言传输指数的描述存在偏差^[94]，国内学界开展汉语背景的相应研究工作十分必要。

(3) 国际领域对声掩蔽措施的研究日益深入，调查与实验研究均证实在中加入掩蔽声可以有效提高言语私密性，降低认知干扰。探究掩蔽声类型和声压级、在空间上的呈现方式、员工舒适性体验、隐蔽性能和效率，以及各因素之间的关系，成为近年学界的研究热点。相比之下，我国的相关研究滞后，应用层面的探索更为有限，需要在学术研究层面深入探索，技术应用上扩大实践和反思，以形成可以推广应用的技术方案。

(4) 心理学、工效学、声景学等交叉学科的研究方法和技术，为开放式办公空间声环境的健康问题提供了新的视角和技术支撑，如人因技术领域的生理指标测量技术、眼动追踪技术等，可以从客观上衡量声环境因素带给办公人员的情绪影响和认知干扰；结合VR虚拟现实的全景音频体验可以更为便捷地进行声环境体验或认知干扰的实验研究，也可以在改造项目中，进行目标效果的呈现和检验。这些技术在人居环境健康领域正逐渐被使用并发挥重要作用，在开放式办公空间声环境的健康领域，利用相关技术的研究刚刚起步，借助这些交叉学科的技术经验，预期将产生较大的学术效益和实践效益。

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Summary for “健康环境视角下开放式办公空间声环境问题及影响”

Problems and impacts associated with the acoustic environment of open-plan offices from the perspective of healthy environment

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The environmental healthfulness of office spaces can ensure the physical and mental health of office workers. The acoustic environment, in particular, influences the emotional health and work performance of them significantly. In the past decades, continuous and in-depth research conducted by the academic community has achieved abundant helpful results based on the extensive application of open-plan offices and the unique acoustic problems associated with the openness of space. This study used the Web of ScienceTM core collection as the data source and employed the visual profiling tools of CiteSpace to analyse domestic and international literatures on environmental and architectural acoustics, psychoacoustics, environmental psychology, ergonomics, human factors and other related fields and then summarise research hotspots and outcomes as well as critical health-related problems and their impacts.

Previous studies have reported that the influence of indoor noises is greater than that of outdoor noises. The primary source of noise in an open-plan office is “irrelevant speech”, which is a background conversation sound between other colleagues; further, “speech privacy” is the most critical problem associated with the acoustic environment of the open-plan office. The language transmission index (STI) can appropriately characterise the speech privacy of a space. Additionally, based on the research results of “Speech Prediction Method” and “STI-Ergonomic Model”, the International Organization for Standardization has formulated ISO3382-3, an acoustic environment measurement standard for open-plan offices. By utilising an appropriate translation method, China has developed and formulated the national standard GB/T36075.3.

The adverse effects of the acoustic environment problems can be summarised into “psychological interference” and “cognitive interference”. The former results in “sound annoyance” and strengthens negative emotions, including fatigue, stress, and irritability, whereas the latter reduces cognitive performance and increases the cognitive load of the workers. Thus, the office workers’ acoustic environment experience and its health impact are related to the space type, work type, language type, and individual differences; however, the conclusions are insufficient. Acoustic masking is an effective methodology to improve the speech privacy in a space, but it can cause acoustic comfort problems. Exploration of the types and sound pressure levels of masking sounds, their spatial presentation, workers’ comfort experience, masking performance and efficiency, and the relationship between these factors has become a research hotspot in recent years.

To ensure the healthfulness and comfort of the acoustic environment of open-plan office, further promotion at the level of theoretical research as well as technical inquiry and management should be conducted. This includes establishing an evaluation criterion that fits the characteristics of China’s office space and the Chinese language environment as soon as possible because it forms the basis for occupational health management, office building design, and acoustic environment transformation. Meanwhile, the academic investigation and application exploration of the technical methods, such as acoustic masking, is being promoted to enhance the acoustic performance of the open-plan office to obtain a technical solution that can be promoted and applied. In addition, the exploration of the sound-related environmental health issues associated with the open-plan office using advanced technologies, such as the physiological measurement technology, eye-tracking technology, and virtual reality presentations, is expected to obtain considerably significant academic benefits.

open-plan offices, acoustic environment, speech privacy, irrelevant speech, emotional influence, cognitive interference

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