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·综 述·

脑力疲劳测评方法的研究进展

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[摘要] 脑力疲劳，最早称为脑疲劳，是临床常见的疲劳类型之一。近年来，在经济文化产业尤其是军事作业人群中，由于脑力劳动的强度和比例逐步上升，脑力疲劳发生率亦逐步上升。目前，脑力疲劳已成为疲劳预防和治疗的重要研究领域。脑力疲劳程度的测定是开展相关研究的基础，对其防治具有重要意义。然而，由于脑力疲劳具有强烈的主观性且其发生机制并不十分明确，目前测评方法种类繁多，仍无统一的标准。本文就现有脑力疲劳的测评方法进行综述，将现有评估方法主要分为症状学评估、心理行为学评估、生理学和生物化学评估三大类，探讨各类评估方法的主要内容和原理，以期为相关研究提供一定参考。

[关键词] 脑力疲劳；量表；体征和症状；心理学；脑电描记术

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Assessment methods of mental fatigue: an update

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[Abstract] Mental fatigue, first known as brain fag, is one of the common clinical fatigue types. Due to the increase of the intensity and proportion of mental work, mental fatigue has an increasing prevalence among the people working in all fields especially, especially in the military field. In recent years, mental fatigue has become an important part of fatigue-relative research. How to prevent, control and alleviate mental fatigue is an important issue, which is based on evaluating or determining the degree of mental fatigue. Because mental fatigue has strong subjectivity and its mechanism is still unclear, there are many evaluation methods, but with no unified standard. This article reviews the evaluation methods of mental fatigue, including symptomatic, psychobehavioral, and physiological and biochemical assessment, and discusses the main contents and principles of various evaluation methods, so as to provide reference to mental fatigue research.

[Key words] mental fatigue; scales; signs and symptoms; psychology; electroencephalography

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脑力疲劳，最早称为脑疲劳，由 Prince[1] 在 1960 年研究非洲儿童学习状态时提出，当时被认为是一种以主观倦怠感、认知功能下降、睡眠倾向性为主要表现的人体状态。其后，随着社会科技的不断发展，这种影响工作效率的特殊精神与心理状态逐渐得到广泛关注。目前，虽然国际上尚未对脑力疲劳的确切定义达成共识，但精神与心理学界普遍认为其与体力疲劳相对[2]，是疲劳的一个子分类[3]，是一种特殊的消极性精神状态[4-5]，主要表现为倦怠、警觉性降低、动机缺乏、认知活动能力下降和工作效率降低[6-8]。近年来，由于机械化和智能化产业的不断发展，在经济文化产业工作者尤其是军事作业人群中脑力劳动的强度和比例逐步上升[9-11]，因此如何预防和改善脑力疲劳已成为疲劳相关研究领域的重要课题。如何对脑力疲劳的程度进行测评是开展相关研究的基础。由于脑力疲劳具有强烈的主观性且其发生机制并不十分明确，测评方法很多，却始终缺乏统一的标准。目前，主要根据临床表现将评估方法分为自觉症状、作业能力和生理功能 3 个方面。本文就现有脑力疲劳的测评方法进行综述，以期为后续相关研究提供一定的借鉴和参考。

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1　症状学评估

症状学表现是脑力疲劳最主要和直接的表现，从症状学尤其是患者的主观自觉症状角度对其程度进行评估是最直观的手段之一，也是目前相关研究中应用最多的评估方法。脑力疲劳者的主要症状表现包括主观方面的疲劳倦怠感、警觉性降低引起的嗜睡倾向，以及伴随而来的紧张焦虑等不良精神情绪体验 3 个方面。

1.1　*主观疲劳感的评估*　对于脑力疲劳的疲劳主观感觉的评估，目前多采用自评量表法让受试者进行主观自评。现有疲劳量表可以分为单维评估量表和多维评估量表 2 类。前者多仅对整体疲劳感的程度、发生频率等单一因素进行评估，如疲劳严重度量表（fatigue severity scale，FSS）等[12]；而后者则是对疲劳感进行分类评估，如将疲劳感分为生理疲劳（physical fatigue）、精神疲劳（mental fatigue）、总体疲劳（general fatigue）等，代表性的有多维疲劳量表（multidimensional fatigue inventory-20，MFI-20）等[13]。研究发现，脑力疲劳可在一定程度上对体力造成影响[14]，故目前多维疲劳量表的使用频率相对更高。当然，由于单维疲劳量表具有直观、简洁、易被受试者接受的特点，在疲劳的定性评估研究中亦广泛应用。目前临床研究常用的疲劳自评量表见表 1[12-13,15-31]。

表 1　临床研究中常用的疲劳自评量表

Tab 1　Self-evaluation scales of metal fatigue

Scale	Introduction	Reference
Fatigue severity scale (FSS)	FSS has 9 items with 1-7 score for each one. The sum of all the scores of every item correlates with severity of fatigue and fatigue interference to life. Both the English and Chinese versions have high validity	[12,15]
Fatigue scale-14 (FS-14)	FS-14 has 14 items with score of 0 or 1 for each one. Items 1-8 evaluate physical fatigue, and items 9-14 evaluate psychological fatigue. The severity of the two kinds of fatigue is measured by their sum of scores. Both the English and Chinese versions have high validity	[16]
Fatigue symptom inventory (FSI)	FSI has 14 items with 0-10 scores for each one. It assesses the severity and frequency of fatigue, perceived interference associated with fatigue, and daily pattern of fatigue. All these are evaluated by the score of corresponding items. Both the English and Chinese versions have high validity	[17-18]
Multidimensional fatigue inventory-20 (MFI-20)	MFI-20 has 20 items covering general, physical and mental fatigue, and reduced activity and motivation associated with fatigue. Each item is assessed by a 5-point Likert-type scale. Severity of fatigue is measured by the sum of all the items. Both the English and Chinese versions have high validity	[13,19]
Brief fatigue inventory (BFI)	BFI has 9 items with visual grade scaleplate for each one. Fatigue severity is assessed by the sum of the value of scale on corresponding scaleplate. Both the English and Chinese versions have high validity	[20]
Fatigue assessing instrument (FAI)	FAI has 29 items with 1-7 score for each one. The sum of all the scores of every item correlates with severity of fatigue	[21]
Borg's rating of perceived exertion scale (RPE)	RPE is always used to evaluate the perceived fatigue caused by physical exertion. It rates perceived fatigue as grade 6-20 with higher grade indicating severe fatigue	[22]
The functional assessment of chronic illness therapy-fatigue (FACIT-F)	FACIT-F has 13 items covering tiredness, weakness, and difficulty managing daily activities due to fatigue. Items are scored on a 5-point Likert-type scale. Severity of fatigue is measured by the sum of all the items, with higher scores indicating less fatigue. Both the English and Chinese versions have high validity	[23-24]
Mental fatigue scale (MFS)	MFS has 14 items focused on mental fatigue and covering the assessment of general fatigue, lack of initiative, memory problems, slowness of thinking, sensitivity to stress, decreased sleep quality, ect.. The scale has a cut-off value＞10.5 and healthy controls report a total mean value of the MFS at a score of approximately 5	[25-26]
Visual analogue scale (VAS)	VAS is the simplest scale for the quick assessment of fatigue severity. It asks participant to mark his feeling on a line with scales from 0 to 100, with 0 representing for no feeling of fatigue and 100 for extremely burned out	[27]
NASA-task load index (NASA-TLX)	NASA-TLX comprises 6 factors of mental, physical and temporal demand, performance, effort and frustration. Each factor is scored as 0-20. The sum of all the scores reflects the severity of mental fatigue caused by work load	[28-29]
Samn-Perelli fatigue checklist	Samn-Perelli fatigue checklist is mainly used to evaluate the fatigue severity of pilot. It rates fatigue into 7 grades based on the subjective feeling of awakening, alertness, and burned out. Higher grades indicated a higher level of fatigue	[30]
Checklist individual strength (CIS)	CIS has 20 items scored by 7-point Likert-type scale respectively, involving fatigue severity, concentration, motivation and activity level. The total CIS cut-off point is 76 for fatigue with higher scores indicating higher level	[31]

NASA: National Aeronautics and Space Administration of America

1.2　嗜睡倾向及精神情绪评估　睡眠倾向或嗜睡感是大脑警觉性降低的主要外在表现，因而也是脑力疲劳的主要评估对象之一。目前，对脑力疲劳者嗜睡倾向的评估主要包括客观他评和主观自评两个方面。客观他评多用视频监控观察受试者在作业过程中发生的自觉或不自觉的点头、哈欠等表现的次数进行评估[32]；主观自评多用疲劳相关睡眠评估量表得以实现，目前常用的量表有匹茨堡睡眠质量指数（Pittsburgh sleep quality index，PSQI）[33]、斯坦福睡眠量表（Stanford sleep scale，SSS）[34]、卡罗琳斯卡嗜睡量表（Karolinska sleepiness scale，KSS）[35]等。

在脑力疲劳时大脑认知和作业能力下降，无法正常完成现有作业任务，常伴发头痛、头晕、视物模糊等相关非特异性自觉症状以及烦躁、焦虑等不良情绪[36]，其严重程度可以在一定程度上反映大脑认知与作业能力，因此也逐渐成为脑力疲劳量表评估的重要部分。目前临床研究中也多使用主观自评量表进行评估，如简明心境状态量表（profile of mood state questionnaire fatigue，POMS-fatigue）[37]、情境动机量表（situational motivation scale，SIMS）[38]、精神症状综合量表（comprehensive psychopathological rating scale，CPRS）[39]等。

2　心理行为学评估

作业能力下降是脑力疲劳的重要行为学表现之一，通过心理行为学测试对脑力疲劳者的作业能力进行评估可以在一定程度上反映脑力疲劳的严重程度。目前，主要对大脑认知能力及警觉性进行评估。其中大脑认知能力评估主要包括记忆力、逻辑运算能力、时空估计能力、决策能力、注意力等多方面进行评估，其常用评估方法有记忆试验[40]、运算测试[41]、爱荷华决策任务测量[42]、注意力划消测验[43]等。而由于大脑警觉性在行为学上主要表现为人体对各种时限性任务的反应能力或反应时间，因此实际试验过程中多用反应能力测评对其进行评估，其常用方法主要包括任务测试如精神运动警觉性任务（psychomotor vigilance task，PVT）[40]和反应时测试如致闪烁临界频率（critical flicker frequency，CFF）[44]等。

需要指出的是心理行为学评估需要在一定程度上唤醒受试者的部分脑区活动功能，对同一脑力疲劳者进行多项目、长时间的行为学测试会在一定程度上影响其脑力疲劳的程度。因此，目前亦有研究者提出用组合行为学测试，如 trail making test[45]、世界卫生组织神经行为核心测试组合（World Health Organization neurobehavioral core test battery，WHO-NCTB）[46]等，对受试者进行一次性、短时间的评估，以尽可能减少对受试者原有脑力疲劳程度的影响。

3　生理学和生物化学评估

脑力疲劳的症状学评估多由受试者进行主观自评，而心理行为学测试所得评估结果常与测试时间、项目复杂程度等多种因素相关，因此这 2 种方法的实施应用均有一定的局限性。如何对脑力疲劳程度进行客观、精确测量逐渐成为脑力疲劳评估的重要研究内容。越来越多的研究表明，脑力疲劳与神经电生理活动、能量及多种物质的代谢具有一定联系，因此生理参数或生物化学指标的测定与研究已成为其客观化评估的重要内容。

3.1　人体电生理参数评估　神经电生理活动是大脑的主要生理活动之一，脑力疲劳的客观化测定研究最早则从人体电生理参数的测定展开。

脑电活动的监测是本研究领域的重点和核心，其主要监测技术为脑电图及其相关衍生技术。脑电图是最早用于评价脑力疲劳的客观指标，也一度被认为是评价脑力疲劳最可靠的标准。早期研究发现，疲劳状态常伴有脑电枕区 α 节律抑制和顶区 α 节律波活动增加[47]，而在驾驶疲劳者中又可观察到枕叶和顶叶的 α 波向额叶进行扩散[39]。近年研究发现，疲劳时的脑电改变除 α 节律波外，还与脑背外侧前额叶皮质和后扣带回皮质中 δ 带节律的减少，前额叶、下额叶、后颞叶和枕叶的 β 波节律下降以及 $[(\alpha+\theta)/\beta]$、α/β、$[(\alpha+\theta)/(\alpha+\beta)]$、$\theta/\beta$ 波比例增加相关[31,48]。

除脑电图中各节律波的改变外，脑电事件相关电位（event related potential，ERP）也是脑电活动监测的主要评估手段之一。ERP 是大脑对刺激信息进行认知加工时发生的电生理变化，是反映大脑接收刺激信息到对之做出相应反应这一信息处理过程的理想指标，具有良好的瞬时分辨力，可以更加直接地评估中枢神经系统对外界事物的处理能力。最早 Biferno[49]在对疲劳进行分级研究时

发现，ERP 中的 P300 电位幅值与疲劳程度密切相关，其后 Okamura[50]又发现 P300 电位的潜伏期延长亦与脑力负荷程度相关。目前 P300 已在脑力疲劳相关研究中得到广泛应用[51-52]。随着 ERP 监测技术的发展，研究者还发现脑力负荷还与 ERP 中的 N100、N200、失匹配负波（mismatch negativity，MMN）的出现频率有关[53]，而由认知活动诱发的脑力疲劳程度还与 P1、N1 波的出现频率[54]及 ERN、CNV 波的波幅大小[55]有关。

由于视觉刺激是多数认知活动的基础，故眼的电活动可在一定程度上反映脑力疲劳程度，有研究者认为眼动诱发电位可以作为脑力疲劳的一项预警指标[56]。此外，虽然早在 19 世纪 80 年代就发现驾驶疲劳时心率明显下降[57]，但 Van Cutsem 等[58]的系统评价发现心率、血乳酸等传统认为与疲劳相关的因素仅与体力疲劳相关，而与脑力疲劳并没有相关性。因此，心电活动是否与脑力疲劳相关仍需要进一步研究证实。

3.2　生物化学指标评估　在疲劳研究早期，生物化学指标的检测由于涉及到侵入性技术而未能得到广泛研究和应用。但随着传感器及脑电超慢涨落图技术（encephalofluctuograph technology，ET）等非侵入性检测设备的发展，以生物化学指标水平评估脑力疲劳程度的研究日益增多。虽然目前与脑力疲劳相关的生物化学指标的研究尚未完善，但也取得了一定成果，可在一定程度上为脑力疲劳的客观化评估提供参考意义。

脑力疲劳的发生与神经系统密切相关，因此神经递质水平的改变与脑力疲劳的发生关系密切。现有研究表明，脑力疲劳时常伴有多巴胺[59]、去甲肾上腺素[60]水平下降，以及 5-羟色胺水平上升[61]。除了神经递质以外，认知活动还可使大脑皮质中的腺苷水平上升，从而抑制中枢神经系统的兴奋性，诱发脑力疲劳[62-63]。而 Coqueiro 等[64]通过检测大鼠在持续认知活动诱发脑力疲劳试验前后血清氨基酸水平发现，脑力疲劳时血清支链氨基酸、酪氨酸、半胱氨酸、甲硫氨酸、赖氨酸和精氨酸水平均明显下降。此外亦有研究发现血清皮质醇及超氧化物歧化酶水平的升高与脑力疲劳呈正相关[65-66]。

4　小结与展望

症状学评估、行为学评估及生理学和生物化学评估是目前脑力疲劳评估的 3 个主要方面。前两者的实施需要依赖受试者的主观感受或行为表现，具有一定的主观局限性，但使用方便、操作简单、费用低廉，依然是脑力疲劳评估的主要方法。不过需要指出的是，这两类方法的具体评估量表及测试方法种类多样，评估内容及便捷程度各有不同，需要根据不同的研究设计合理选取。生理学和生物化学评估是客观化评价脑力疲劳的主要手段，具有很好的客观实在性，但由于脑力疲劳的发生机制尚未能完全阐明，加之大脑功能的复杂性，包括脑电图在内的多种测定方法仍处于不断发展之中，因此在实际应用中量化标准的选择方面具有一定的困难。

随着科技发展及研究的深入，脑力疲劳的评估除以上较为公认的方法外，各种新兴理论与技术也层出不穷。目前基于脑电图评测原理，已有研究者提出以脑电近似熵对脑力疲劳程度进行量化计算[67]或用功能磁共振成像对神经元活动引发的血液动力改变进行测量[68]，以直观显示受外界刺激时的脑部活化区域，进而评估脑力疲劳时各脑区的功能状态；此外，也有中医研究者对疲劳相关中医证候理论[69]、脑力疲劳的舌象评定法[70]和脑力疲劳者的腧穴热敏化现象[71]等进行了探索。

虽然脑力疲劳的评估方法日趋多样化，但国际上仍无统一标准可循，这给相关研究的发展造成了一定的困扰，是本研究领域亟需解决的主要问题。

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