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Evaluation of Cognitive Symptoms Following Concussion

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Abstract The assessment of cognitive symptoms following concussion has evolved over the last several decades as a distinct focus in research and an essential component of clinical decision making and management. The aims of this paper are to (1) identify issues related to assessment of postconcussion cognitive functioning and (2) provide a review of common self-report and performance-based measures, including computerized-based assessments (CBAs), and, more traditional, comprehensive neuropsychological evaluations. We conclude that (1) there has yet to emerge one cognitive-symptom measurement method that can be considered the "gold standard" for all settings, (2) the usefulness of cognitive symptoms assessment findings in the clinical management decisions rests a great deal on the background of the practitioner, and (3) cognitive-symptom assessment needs to be considered in the context of a broader evaluation of other postconcussion symptoms.

Keywords Cognitive symptoms · Neuropsychological functioning assessment

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Introduction

Concussion, by definition, manifests in transient, immediate altered mental status changes and, commonly, longer lasting cognitive functioning changes, which, for the large majority of sufferers, resolve within a few days to a few weeks or months [1] Self-reported and/or measureable postconcussion cognitive symptoms most frequently involve declines in attention, mental processing speed, and memory efficiency [2, 3]. Although typically mild in degree, these declines, while present, can often interfere noticeably with a sufferer's functional status, making accurate assessment an essential part of the clinical management of concussion. Notably, given the likelihood of multiple other types of symptoms following concussion (e.g., headache, sleep disturbance, mood problems), the evaluation of cognitive symptoms should not be considered in isolation and needs to be a part of a broader medical and psychological evaluative process in order to inform diagnostic impressions and optimize management.

The assessment of cognitive functioning following concussion has evolved over the last several decades as a distinct focus in research as well as in various clinical and legal settings. The purpose of this paper is to summarize approaches to the assessment of cognitive functioning following concussion. At the outset, it should be noted that, in our reading of the literature and clinical experience, assessment of postconcussion cognitive functioning can be influenced by a number of factors, including, for example, evaluation method (self-report, psychometric testing), time since injury, context of the injury (e.g., military, sports, motor vehicle accident), purpose of the evaluation (e.g., return to work/school/return-to-play, legal), setting of the evaluation (e.g., injury scene, emergency room, healthcare professional office), test psychometrics (e.g., test sensitivity/specificity, reliability), and last, but certainly not least, the professional background of the

evaluator. That such a relatively high number of influencing factors are present underscores the fairly complex nature of the cognitive evaluation landscape that has evolved in clinical management of concussions.

The influence of time-since-injury on postconcussion cognitive functioning is particularly noteworthy, as it relates to the natural course of cognitive-symptom presentation following concussion and, in turn, type and frequency of evaluation at given stages of recovery. Although there is individual variability in the course of symptom presentation and recovery, group data suggest that the most severe concussion-related cognitive symptoms are experienced immediately after injury, with delayed onset being very uncommon [4]. Moreover, there is general agreement in the literature on favorable outcomes, with recovery from concussion or uncomplicated mild traumatic brain injury in the vast majority of sufferers occurring within days, weeks, or a few months of injury [5–10] However, in a minority of individuals, cognitive symptoms are noticed past the normal recovery window of a few months and often, in combination with other symptoms (e.g., headache, emotional changes), form the basis of a diagnosis of postconcussion syndrome.

For the purposes of this chapter, we will use the terms "concussion" and "mild traumatic brain injury" synonymously, as this allowed for a more robust review of the literature on available evaluation procedures and issues (se McCrory et al. [11], for discussion of the terms).

Essential Evaluation Ingredients

Cognitive functioning changes following concussion are typically mild in degree and can often be nonspecific nature from an etiologic standpoint. Outside of many, though certainly not all, sports and military settings, postconcussion evaluations of cognitive functioning are done without the benefit of preinjury baseline cognitive functioning data for comparison purposes. As such, for the typical postconcussion evaluation of cognitive functioning, the challenge for the clinician is to not only ensure valid assessment of cognitive functioning but also gain sufficient information to determine if an actual concussion-related change in the person's cognitive abilities from their preinjury status has occurred. To meet these challenges, even in settings where preinjury cognitive baseline data are available, it is essential that the evaluation process includes not only strategies for direct assessment of cognitive symptoms but also for gathering multiple lines of information to form impressions about the extent to which preinjury factors (e.g., medical, psychological, learning/academic histories) and co-occurring postinjury factors (e.g., headache, psychological status, motivation) may be influencing a person's cognitive presentation. In these latter regards, any assessment of postconcussion cognitive functioning should ideally not be done in isolation of the person's preinjury history and potential postinjury cognitive-symptom maintenance factors and, as recommended by Klonoff and Dawson [12], follow a "holistic" integrative approach.

Cognitive Symptom Assessment Strategies

Cognitive functioning assessment in the clinical setting is based typically upon a combination of self-report (patient/collateral informants) and some form of performance-based psychometric testing. We will tackle the area of self-report assessment first, then psychometric strategies.

Self-Report Strategies

Perceived changes in cognitive functioning on the part of the concussion sufferers becomes an integral part of the clinical management, as they impact the persons general sense of well-being and can influence diagnostic impressions and decisions regarding return to preinjury activities and initiate further types of evaluation. Self-report of cognitive functioning can be obtained through interviews as well as psychometric means. Notably, the clinician should be aware that self-report assessment method (e.g., interview versus symptom-checklist) can affect the concussion-symptom expression by the patient, as, for example, studies by Iverson et al. [13] and Edmed and Sullivan [14] found that psychometric-based assessment (i.e., checklists) elicited significantly more symptoms than interview-based assessment.

Interview

The use of interviews allows the clinician to evaluate pre-to-postconcussion changes in cognitive functions as well as effects on daily functioning, at least in terms of the perception by the patient and/or collateral informant (e.g., family member). Additionally and potentially even more importantly, by way of interview, the opportunity for obtaining a detailed history of the patient's medical, psychosocial, and developmental history is present, allowing the skilled clinician to explore the extent to which factors, other than concussion, have been shown to potentially influence the person's experience cognitive difficulties.

Psychometric Self-Report Measures

Adding structure to the self-report strategy has been the development and widespread use of psychometric instruments (i.e., questionnaires, scales, checklists) designed specifically to obtain patient-reported information on a wide range of symptoms following concussion, with embedded items specifically targeting perceived cognitive changes. The intent of

these instruments is to provide a more systematic examination of cognitive and other possible concussion-related symptoms, whereby specific, common postconcussion symptoms are listed. Cognitive areas queried by these instruments are limited and commonly involve only attention, processing speed, and memory. Typically, these measures have individuals with concussion identify the presence of a given symptom and, if present, grade its intensity on a Likert-type of scale. Several such instruments are now available and used in or adapted for a variety of settings (e.g., research, emergency room, athletic event, military environment, physician office). As provided by Alla et al. [15] and our own review of the literature, examples of such self-report instruments include the following:

Acute Concussion Evaluation (ACE)—Physician/Clinician Office Version [16]
The Post-Concussion Symptom Scale (part of ImPACT, a computerized assessment tool) and its variants [17]
Post-concussion Symptom Assessment Questionnaire (PCSQ) [18]
Concussion Resolution Index (CRI) Post-concussion Questionnaire [19]
Sport Concussion Assessment Tool (SCAT): Post-concussion Symptom Scale [20]
Concussion Symptom Inventory [21]
British Columbia Post-concussion Symptom Inventory [22]

In their critical review article, Alla et al. [15] noted that self-report instruments vary on a number of factors, including choice and number of symptoms, format (paper and pencil versus computer), and response type (e.g., continuous scale versus dichotomous scale). For users of such instruments, Alla et al. called into question the psychometric properties of commonly used instruments, remarking that many of the instruments did not follow psychometric standards in their development, leaving much to be desired in terms of knowledge about the reliability and validity of a given self-report instrument. Moreover, based on their findings that symptom endorsement differed significantly by evaluation method (questionnaire versus interview), Iverson et al. [13] recommended that clinicians should exercise caution when interpreting findings from self-report questionnaires, given potential validity issues involving, for example, the possibility of over-endorsement and the nonspecific nature of endorsed symptoms.

Summary: Self-Report Strategies

Self-report of postconcussion cognitive symptoms is an essential part of the clinical evaluation, as it promotes a patient-centered approach to treatment, guides the type of and need for follow-up care, and can influence clinical decision making regarding return to preinjury activities. Nevertheless, as noted in the literature, clinicians need to exercise a healthy degree of caution when considering self-report findings, regardless of method used (interview and/or questionnaire), given potential threats to validity such as unintentional and intentional response bias on the part of the respondent, resulting in under or over-endorsement of cognitive symptoms. Factors noted in the literature that could contribute to self-report response bias of concussion-related symptoms include poor awareness of cognitive problems, reinforcement for minimization of symptoms (e.g., return-to-play in a sports setting), reinforcement for over endorsement (e.g., compensation-related setting), misattribution of cognitive symptoms to concussion (e.g., memory problems due to depression), and nocebo effect (patient expectancies of concussion symptoms [13]).

Performance-Based Measurement

The potential validity issues associated with subjective self-reporting of cognitive symptoms has led to the entry of performance-based strategies into the evaluation of postconcussion cognitive symptoms in a variety of clinical settings. These strategies have, in many respects, been derived from neuropsychological evaluation methods and are employed to provide a systematic, objective method of quantifying the type and severity of cognitive functioning symptoms. Standardized administration procedures are used in the evaluations and, in turn, allow comparisons of a given individual's performance to existing normative data or, in the case of preconcussion or prior testing (e.g., preinjury baseline testing), to existing data on the individual. Theoretically, it is through such comparisons to normative and/or preexisting cognitive data that impressions regarding changes in cognitive functioning stemming from concussion can be made.

Performance-based measurement of cognitive functioning following concussion can take the form of brief mental status examination, computer-based assessment, and more traditional, comprehensive neuropsychological evaluation. Regardless of method used, preconcussion data on cognitive functioning in clinical setting, outside of certain sports and military settings, are typically not available for comparison, requiring the clinician to form impressions based largely on normative data and estimates of baseline cognitive functioning. The type of performance-based method selected depends commonly upon time since injury, injury/evaluation setting, healthcare provider training and preference, reason for the assessment, and, of course, availability of testing instruments or tools.

Mental Status Examinations

The use of general mental status examinations, e.g., Mini-Mental Status Examination (MMSE) [23] or Montreal Cognitive Assessment (MoCA) [24] in detection of cognitive

functioning symptoms is common, owing to their brevity, ready availability, familiarity, and relative ease of administration. While offering a standardized and a potential valuable evaluation tool, mental status examinations can lack sufficient sensitivity in detecting postconcussion cognitive symptoms, which are typically mild in severity [25]. Of the two popular mental status examinations, MMSE and MoCA, the MoCA has been found in many instances to have greater sensitivity to mild cognitive dysfunction than the MMSE [26] though setting appropriate cut-scores that optimize sensitivity and specificity continues to be an issue that needs to be further investigated [27].

Included in this section on mental status examination is the Standardized Assessment of Concussion (SAC) [28, 29]; which is incorporated into the Sports Concussion Assessment Tool (SCAT), now in its 3rd edition (SCAT-3) [30]. The SCAT-3 offers a non-computer-based standardized tool for assessing a multiple number for postconcussion symptoms in persons aged 13 and older at the injury site (e.g., sideline) immediately following injury, and at postinjury times for comparison. In terms of cognitive symptoms, the SAC takes about 5 min to administer and provides brief measurement of orientation, basic attention skills or concentration (working memory) and verbal memory (immediate and delayed). As summarized by McCrea [4], the SAC has been extensively studied and found to have good sensitivity and specificity. The SAC can be used to track recovery from concussion without preinjury baseline data, though is potentially more useful in this regard (i.e., increased sensitivity and specificity), when preinjury comparison baseline data is available [30].

Computerized-Based Assessment

Over the last two decades, there has been a marked focus on and increase use of computer-based assessment (CBA) of cognitive functioning in persons with concussion as an alternative to traditional paper-and-pencil neuropsychological assessment. The use of CBA strategies has been particularly evident in sports and military settings, where there is a need for rapid, objective assessment of cognitive functioning in a large number of individuals for the purpose of guiding decisions regarding return to preinjury activities [31]. As cited by several authors, e.g. [32, 33], CBAs have several appealing, presumed advantages over traditional paper-and-pencil neuropsychological psychometric measurement, including (1) potential to test a large number of individuals efficiently, (2) ease of administration, (3) convenient access to tests, (4) availability of alternative forms of tests to reduce practice effects for multiple intra-individual comparisons over time, (5) reduced training needs for administration, and (6) ease of results interpretation (e.g., use of interpretive algorithms). The ease of administration and availability of alternate forms allow a longitudinal approach to assessment, whereby preinjury baseline data on cognitive functions can be obtained and compared to postinjury data, with the goal of affording more precise management of concussion by way of increased accuracy in the measurement of change in cognitive functioning and rate of recovery. As Resch et al. [33] observed, the ease of administration and supposed reduced need for involvement of professionals trained in interpretation of findings have facilitated the wide adoption of the CBAs in sports and military settings. However, as noted by Coppel [31], while offering more widespread assessment precision, this latter growth can be associated with some minuses, as the use of computerized evaluations can place an overemphasis on managing the aftermath of concussion on cognitive functioning change statistics rather than the complex array of factors that can, in many cases, affect outcome.

CBAs employed for use in sports and military settings use a serial, multi-dimensional assessment approach, whereby multiple cognitive domains can be tested longitudinally by several, brief screening measures in a relatively short timeframe (commonly less than 30 min). CBA measures are based typically on traditional paper-and-pencil neuropsychological tests and often screen for non-cognitive, postconcussion symptoms (e.g., balance). Common cognitive domains assessed by CBAs include processing speed, reaction time, attention/concentration, and verbal and visual memory. A number of CBA instruments have been developed over the years for research and commercial use and brief summaries of a sample of those currently in use and commonly referenced in the literature are given below:

1. Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT): ImPACT is cited as the most widely used computer-based assessment tool and was developed originally by Lovell and colleagues [34] for sports settings, with the stated purpose of assisting care providers with return-to-play decisions. The measurement tool consists of three components: demographic data, neuropsychological tests, and the postconcussion symptom scale (PCSS). The assessment tool takes about 20–25 min to administer. Cognitive functioning abilities are assessed by six neuropsychological tests, targeting attention, memory, processing speed, and reaction time. Five composite scores are yielded and include verbal memory, visual memory, reaction time, processing speed, and impulse control.
2. Automated Neuropsychological Assessment Metrics (ANAM): The ANAM [35] is a composed of set of computer-based assessments of various cognitive areas that can be adapted for a variety of settings, including military and sports settings. It was developed originally for military use through the US Department of Defense with the goal of obtaining pre-deployment cognitive baselines in all members of the USA military for any later

needed comparisons. The ANAM provides a 20-min computerized screening of several cognitive abilities that are likely to be impacted by a concussion—attention, concentration, reaction time, memory processing speed, and decision making (i.e., processing speed, attention, and memory).

3. The CogSport/Axon Cogstate Computerized Cognitive Assessment Tool (CCAT): The CCAT [36] is an online measure of brain functioning for sports settings. It uses a pretest-posttest model and targets psychomotor function, speed of processing, visual attention, vigilance, and verbal and visual memory. Testing is said to take about 10 min to complete.

Reliability and Validity of Computer-Based Cognitive Assessment

Resch et al. [33] recently reviewed the literature on the psychometric properties of several computer-based cognitive assessment tools, including each of the ones cited above. As summarized in the review, test-retest reliability, which is essential for detecting a genuine change in cognitive functioning from baseline to a postinjury point, for each of the tools varied widely across studies. For example test-retest reliability for ImPACT was cited as ranging between 0.23 and 0.88, when using time points typically employed in the sports concussion setting [33, 37, 38] Indeed, Mayers and Redick [39], in their recent review of the literature on the psychometric properties of the ImPACT assessment tool commented that the inconsistency in test-retest reliability raises distinct questions about stability of findings and, therefore, their utility in making return-to-play decisions. The reason for CBAs varying reliability is unclear, though testing environment (i.e., group versus individual administration), differences in computers' measurement accuracy, lack of alternate form equivalences, and test-takers' motivation and psychological status (e.g., depression, anxiety) have all been cited in the literature as possible factors.

Possible effects of motivation on baseline testing have become a more recently recognized threat to the validity of findings particularly in the sports setting. In this regard, Coppel [31] and others, e.g. [33], have noted that certain athletes may be prone to intentionally scoring low (poor effort) on baseline testing, with the goal of decreasing the likelihood of detection of postconcussion cognitive symptoms in order to speed their return to play. Notably, a sizable minority (11 to 35 %) were found capable of completing ImPACT with possible suboptimal performance not being detected (i.e., performance did not violate a standard validity indicator) [40, 41]. That suboptimal effort might occur and not be detected, even if only in a minority of test-takers, requires the clinician to always inspect performances across the entire CBA test battery for validity (i.e., assess whether cognitive findings at a level that could be reasonably expected).

Coppel [31] and Echemendia et al. [42] have argued that CBAs have limited scope in terms of types and extent to which cognitive domains are assessed. More specifically, Coppel [31] argued that, secondary to measurement method (i.e., interaction of the person with a computer screen), all tests are conducted using visual stimuli. As such, by default, CBAs do not measure auditory processing or verbal-auditory memory. Additionally, CBAs test memory functioning exclusively by use of a recognition or cued recall format rather than a free or uncued recall format; the use of a recognition format is considered to be easier and, in turn, potentially less sensitive than a free recall format. This potentially creates a risk of not detecting subtle/mild memory problems commonly experienced by persons suffering concussion.

In summary, CBAs certainly offer a number of appealing features, allowing rapid assessment of cognitive functioning and a longitudinal comparison approach. However, users need to be aware of their limitations, especially in regard to potentially questionable psychometric properties of each tool. Unfortunately, a good number, if not the majority, of CBA users may not have had sufficient training in test development and psychometrics to fully appreciate and interpret accurately data generated by the CBAs [43]. Wherever this lack of training may be present, concerns should certainly be raised about the quality of concussion management decisions using CBA findings alone. Our conclusion is that CBAs provide a potential valuable approach to the assessment of cognitive functioning following concussion, but need to be interpreted by professionals (e.g., neuropsychologists) who have specialized training in test psychometrics and interpretation of cognitive test data in order to optimize clinical management. Moreover, test data generated by CBAs should be considered not in isolation but a part of a broader evaluation of the concussed individual that accounts for other concussion-related symptoms (e.g., headache), relevant facets of the individual's preinjury history, and potential co-occurring postinjury cognitive symptom maintenance or exacerbation factors (e.g., stress, motivation).

Comprehensive Neuropsychological Evaluation

Most, if not all, of the mental status and CBA measures discussed above were derived from paper-and-pencil neuropsychological psychometric test batteries used in more comprehensive assessments. In a comprehensive neuropsychological evaluation, psychometric assessment targets a wide number of cognitive functioning areas as well as emotional functioning, with testing commonly lasting several hours. Typically, the battery employs multiple measures of a given cognitive domain and can target different, specific aspects of a given domain (e.g., basic skills versus complex attention skills, uncued versus cued recall). Most tests used in the evaluation employ a paper-and-

pencil format and are administered in a standardized, face-to-face fashion to an examinee by the neuropsychologist or psychometrist assistant; stand-alone, computer-based tests may also be included in the psychometric portion of the evaluation. Comparable to CBAs, psychometric issues (e.g., reliability, validity, adequacy of norms) need to be considered even with the more traditional tests used commonly in comprehensive evaluations and, once again, prompt the need for specialized training in test psychometrics to optimize interpretation of findings. Importantly, a comprehensive evaluation is not based exclusively on psychometric testing of cognitive functioning, but takes a multimodal assessment approach, incorporating psychometric assessment of emotional functioning and information gathered on interview regarding relevant aspects of the person's psychosocial history, perception of current difficulties, etc., a review of pertinent medical history, and current contextual variables (e.g., medical-legal issues, academic/vocational goals). It is the integration of multiple lines of data or information as well as more thorough assessment of cognitive domains and emotional functioning that sets a comprehensive neuropsychological evaluation apart from the more rapid evaluations described above.

A comprehensive neuropsychological evaluation is resource intensive in terms testing time, face-to-face testing format (i.e., can only assess a single person at a time), and the need for appropriate professional involvement and expertise for interpretation and test administration (i.e., requires a neuropsychologist). The resources (i.e., test materials and neuropsychologist) required for such evaluations are not readily available in all settings. Additionally, a good number of tests commonly used in the evaluations do not have multiple alternative forms for repeated testing, which facilitate tracking trends in cognitive functioning over time. Moreover, within the early phases of recovery from concussion, the extensiveness of comprehensive testing may not provide sufficient incremental value beyond that afforded by brief evaluations in managing the case. However, the incremental value of more comprehensive evaluations in managing cases increases as cognitive symptoms persist beyond the typical recovery time (a few weeks to a few months). When this atypical recovery course occurs, the chances that factors outside injury-related brain changes are playing a greater role in the maintenance of postinjury symptoms increases. Such longer-than-the-norm persistence, in the context of other symptoms (e.g., headache, irritability, depression), often leads to a diagnosis of postconcussion syndrome, which continues to be a controversial designation, given the nonspecificity of symptoms used in making the diagnosis (for review [4]). It is at this postinjury juncture that comprehensive neuropsychological evaluation may be most valuable, especially in regard to determining the nature of subjective, persistent cognitive symptoms as well as teasing out the relative contribution of potential etiologic factors in the case.

Summary and Conclusions

Cognitive symptoms following concussion are common in the early recovery period and their accurate assessment becomes an important part of clinical management and decision making (e.g., return to certain preinjury activities like school, work, or sports activities). However, and as stated at the outset of this chapter, cognitive functioning status following concussion should not be viewed in isolation, given the multiplicity of possible co-occurring postconcussion symptoms and their potential effects on functional status at any stage of recovery.

There has yet to emerge one cognitive-symptom measurement method that can be considered the "gold standard" for all settings. While self-report is readily known to be subject to potential response bias (e.g., overreporting or underreporting error), significant questions regarding the utility of cognitive performance-based measurement, especially CBAs, in managing the early recovery phase have also emerged in the literature. As proposed by Echemendia [44], it may very well be that a "hybrid approach" to evaluation, whereby a combination of performance-based methods (i.e., CBAs and traditional paper-and-pencil neuropsychological tests), be considered as a way to compensate for various methods shortcomings, at least during the early recovery phase. Notably, if cognitive symptoms last past the typical recovery window of a few months, the assessment method of choice becomes a more comprehensive neuropsychological evaluation to ensure that a broad spectrum of cognitive abilities are assessed with well-normed tests and adequate consideration is given to relevant preinjury and co-occurring factors influencing the continuance of cognitive symptoms.

In the end, as many authors have argued, the utility of any cognitive assessment method that is used in the clinical setting rests on the expertise of the practitioner in the interpretation of cognitive test findings, e.g. [4]. In this respect, regardless of recovery stage, it is our recommendation as well as others, e.g. [42], that neuropsychologists, whenever available, should ideally be involved in the cognitive evaluation process, as they have the training and expertise in test administration and psychometric issues and various patient factors (e.g., preinjury learning history, current psychological status, motivation) that could influence a person's cognitive presentation beyond potential effects of the concussion.

Compliance with Ethics Guidelines

Conflict of Interest Myron Goldberg and Renee Madathil each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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