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## Sensitivity and Specificity of the Coma Recovery Scale-Revised Total Score in Detection of Conscious Awareness

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### Abstract

**Objective**—The aim of this report is to describe the sensitivity and specificity of Coma Recovery Scale-Revised (CRS-R) total scores in detecting conscious awareness.

**Design**—Data were retrospectively extracted from the medical records of patients enrolled in a specialized Disorders of Consciousness (DoC) program. Sensitivity and specificity analyses were completed using CRS-R-derived diagnoses of Minimally Conscious State (MCS) or Emerged from Minimal Conscious State (EMCS) as the reference standard for conscious awareness and the total CRS-R score as the “test criterion”. A receiver operating curve (ROC) was constructed to demonstrate the optimal CRS-R total cut-off score for maximizing sensitivity and specificity.

**Setting**—Specialized DoC program

**Participants**—252 patients enrolled in the DoC program (157 male; mean age = 49 years; mean time from injury =48 days; traumatic etiology=127, non-traumatic etiology=125; diagnosis of coma or VS=72, diagnosis of MCS or EMCS=182)

**Interventions**—Not applicable.

**Main Outcome Measure(s)**—Sensitivity and specificity of CRS-R total scores in detecting conscious awareness

**Results**—A CRS-R total score of 10 or higher yielded a sensitivity of 0.78 for correct identification of patients in MCS or EMCS, and specificity of 1.00 for correct identification of patients who did not meet criteria for either of these diagnoses (i.e., were diagnosed with VS or coma). The area under the curve (AUC) in the ROC analysis is 0.98.

**Conclusion(s)**—A total CRS-R score of 10 or higher provides strong evidence of conscious awareness but resulted in a false negative diagnostic error in 22% of patients who demonstrated conscious awareness based on CRS-R diagnostic criteria . A cut-off score of 8 provides the best balance between sensitivity and specificity, accurately classifying 93% of cases. The “optimal” total score cut-off will vary depending on the user's objective.

## Keywords

Disorder of Consciousness; Brain Injury; Sensitivity; Specificity

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## Introduction

Patients emerging from coma after severe brain injury often transition through states of altered consciousness, including the vegetative (VS) and minimally conscious states (MCS). In VS, there is recovery of eye-opening but no behavioral evidence of self or environmental awareness [1]. MCS is characterized by clearly discernible but inconsistent behavioral signs of conscious awareness [2]. Distinguishing MCS from VS during the early stages of recovery is critically important as there is strong evidence that functional outcome is significantly more favorable for patients in MCS relative to those in VS, particularly following traumatic brain injury [3]. Prior research suggests that when diagnosis is made based on clinical consensus of the medical team, approximately 40% of patients diagnosed with VS actually retain conscious awareness [4]. These findings point to the need for more accurate diagnostic procedures.

The Coma Recovery Scale-Revised (CRS-R) is a standardized neurobehavioral assessment measure comprised of six subscales designed to assess arousal level, audition, language comprehension, visuoperception, motor function, oromotor capacity, expressive speech, and yes/no communication in patients with disorders of consciousness (DoC) [5]. The current diagnostic criteria for coma, VS and MCS are embedded in the CRS-R to provide clinicians with a reliable and valid means of establishing a differential diagnosis. Although the CRS-R total score (TS) has been used for prognostic purposes [6], its diagnostic utility has not been investigated. This represents an important evidentiary gap given that prior studies have relied on the CRS-R TS when tracking functional recovery [7], investigating the relationship between behavioral and physiological markers of consciousness [8], and determining the effectiveness of treatment interventions [9]. The primary aim of this report is to investigate the sensitivity and specificity of CRS-R TS in detecting conscious awareness. Results are expected to provide additional empirical support and interpretive guidance for use of the CRS-R total score in clinical practice and research.

## Methods

Following IRB approval to conduct retrospective medical record review, the research team from the medical records of patients enrolled in a specialized DoC program. Eligible patients were admitted to either an inpatient rehabilitation facility or a long-term acute care hospital, both of which rely on a standardized assessment protocol. Between 05/04/2011 and 09/29/2014, obtained at the time of admission into the program were collected for 252 patients (157 male; mean age=49 years [SD=19.7]; mean time from injury=48 days [SD=53]; traumatic etiology=127; mean CRS-R total score=11.27 [SD=5.83]; median=11; coma/Vs=72 (mean=4.64 [SD=2.07]), MCS=138 (mean=12.21 [SD=3.67]), or EMCS=44 (mean=18.89 [SD=3.41]). Non-traumatic etiologies included hypoxia/anoxia, aneurysm, tumors and hemorrhage.

Sensitivity and specificity analyses were completed using CRS-R-derived diagnoses of MCS/EMCS (as denoted by an asterisk or cross, respectively, on the facesheet of the scale) as the reference standard for conscious awareness and the total CRS-R score as the “test criterion”. In this context, sensitivity (or true positive rate) represents the proportion of patients who retain conscious awareness (i.e., have a diagnosis of MCS/EMCS) and are correctly identified by the CRS-R TS. Specificity (or true negative rate) is the proportion of patients who are unconscious (i.e., do not have a diagnosis of MCS/EMCS) and are correctly identified as not in MCS /EMCS by the CRS-R TS (see Supplementary Figure S1 for method used to calculate sensitivity, specificity and accuracy). A receiver operating curve (ROC) was constructed to demonstrate the optimal CRS-R total cut-off score for maximizing sensitivity and specificity for detection of conscious awareness. All analyses were conducted using the [R] statistical software package [10] and Statistical Package for the Social Sciences (SPSS) Version 20.0.

## Results

A CRS-R TS of 10 or higher yielded a sensitivity of 0.78 for correct identification of patients in MCS/EMCS, and specificity of 1.00 for correct identification of patients who did not meet criteria for either of these diagnoses (i.e., were diagnosed with VS or coma). Thus, all patients who obtained a CRS-R TS of 10 or higher demonstrated conscious awareness (i.e., met existing diagnostic guidelines for MCS/EMCS). A cut score of 10 or higher also misclassified as unconscious 22% of those who actually retained conscious awareness.

Table 1 indicates that the optimal combination of sensitivity and specificity is obtained with a CRS-R cut-off score of 8. TS of 8 yields a true positive rate of 93%, true negative rate of 96% and diagnostic accuracy rate of 93%.

As shown in figure 1, the area under the curve (AUC) in the ROC analysis is 0.98 (Figure 1). AUC's between 0.9-1.0 are considered to have “excellent” diagnostic accuracy, based on standard classification guidelines. This finding suggests that CRS-R TSs provide “excellent” accuracy in differentiating individuals who meet diagnostic criteria for conscious awareness from those who do not.

## Discussion

Our findings indicate that a total CRS-R score of 10 or higher provides strong evidence of conscious awareness as defined by existing diagnostic criteria [5]. All patients who received a CRS-R total score in this range were in MCS or had emerged from MCS. On the other hand, a cut-off score of 10 resulted in a false negative diagnostic error (ie, unconscious state) in 22% of cases who actually retained conscious awareness. Thus, approximately one in five patients who demonstrate conscious awareness score below 10. A cut-off score of 8 provides the best balance between sensitivity and specificity (or true positive and true negative rates, respectively), accurately classifying 93% of cases. The “optimal” TS cut-off will vary depending on the user's objective. For example, an investigator wishing to conduct a treatment study focusing exclusively on patients who retain conscious awareness would be advised to adopt a cut-off score of 10 as this will guarantee ascertainment of a homogeneous

sample of participants in MCS/EMCS. On the other hand, a clinician involved in differential diagnostic assessment might adopt a cut-off score of 8, which offers the best odds of concurrently avoiding false positive and negative errors. Clinicians should rely on the full subscale profile when available to ensure the most accurate diagnosis. When relying on TS only, clinicians should be aware that the further the TS falls below 10, the lower the likelihood that the patient retains conscious awareness.

### Study Limitations

The findings from this study should be viewed in the context of several limitations. First, our results may not be generalizable to all patients with DoC. Our sample was comprised of inpatients undergoing rehabilitation during the post-acute phase of recovery, most of whom were in MCS or had emerged from MCS. This may not reflect the larger pool of patients with DoC who are more acutely injured and are receiving care in the intensive care setting. Future studies will need to replicate these results in a larger sample of patients with more variable lengths of time since injury receiving treatment across a variety of healthcare settings.

### Conclusion

Accurate detection of conscious awareness using the CRS-R is best achieved through analysis of the full CRS-R performance profile, which includes all six subscale scores. In the absence of a full CRS-R profile, the total CRS-R score can be interpreted as a marker of conscious awareness with confidence when the score is 10 or higher. CRS-R users should be aware of the advantages and limitations of selecting different TS cut-offs. This report provides data that may help guide decision-making for both clinicians and researchers who wish to use the CRS-R for diagnostic purposes.

### Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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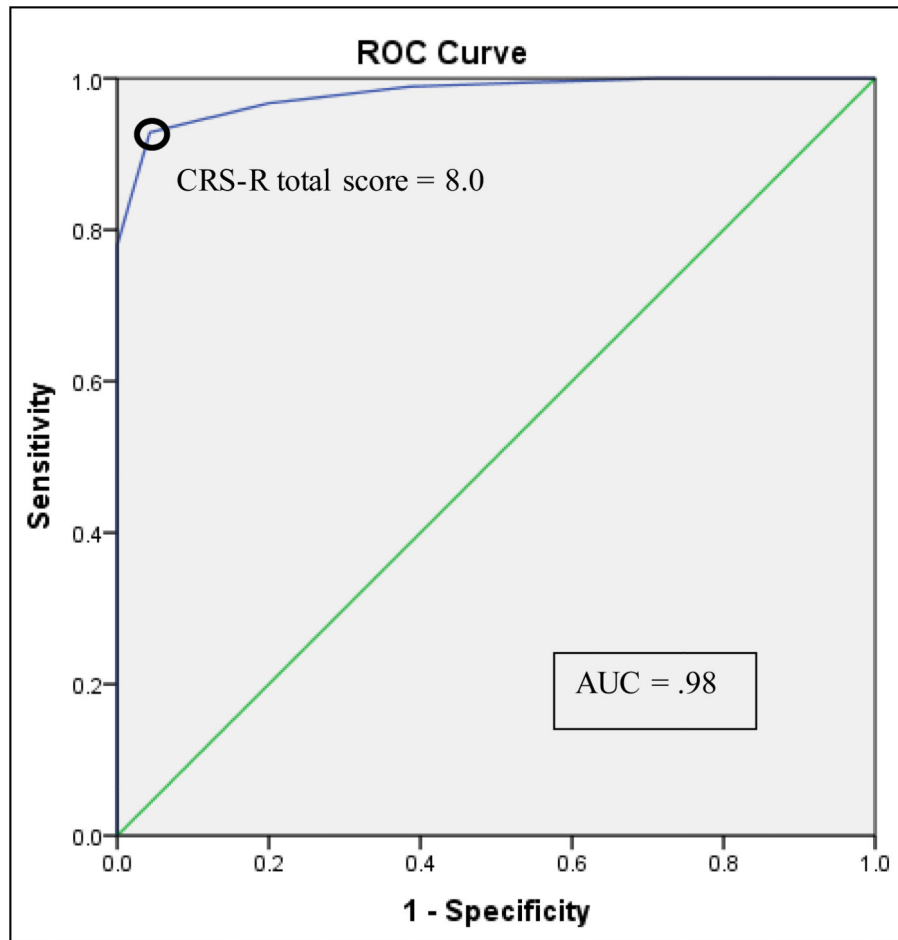
### Abbreviations

<b>CRS-R</b>	Coma Recovery Scale-Revised
<b>DOC</b>	Disorders of Consciousness

<b>VS</b>	Vegetative State
<b>MCS</b>	Minimally Conscious State
<b>EMCS</b>	Emerged from Minimally Conscious State
<b>TS</b>	Total Score
<b>SPSS</b>	Statistical Package for the Social Sciences
<b>ROC</b>	Receiver Operating Curve
<b>AUC</b>	Area Under the Curve

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**Figure 1.** Receiver Operating Curve indicating sensitivity and specificity of CRS-R total scores highlighting the optimal cut-off score of 8. This score yields a sensitivity of 93% and specificity of 96%. The area under the curve is 0.98, indicating that the CRS-R total score accurately differentiates patients who meet diagnostic criteria for conscious awareness from those who do not.

**Table 1**

Sensitivity, specificity, and accuracy rates for detection of conscious awareness at CRS-R total score cut-offs between 7-11.

CRS-R Total Score Cut-off	7	8	9	10	11
Sensitivity	0.97	0.93	0.88	0.78	0.73
Specificity	0.80	0.963	0.97	1	1
Accuracy	0.921	0.937	0.905	0.841	0.802

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