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MULES on the sidelines: A vision-based assessment tool for sports-related concussion

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ABSTRACT

Objective: The Mobile Universal Lexicon Evaluation System (MULES) is a test of rapid picture naming under investigation. Measures of rapid automatic naming (RAN) have been used for over 50 years to capture aspects of vision and cognition. MULES was designed as a series of 54 grouped color photographs (fruits, random objects, animals) that integrates saccades, color perception and contextual object identification. We examined MULES performance in youth, collegiate and professional athletes at pre-season baseline and at the sidelines following concussion.

Methods: Our study teams administered the MULES to youth, collegiate and professional athletes during pre-season baseline testing. Sideline post-concussion time scores were compared to pre-season baseline scores among athletes with concussion to determine degrees and directions of change.

Results: Among 681 athletes (age 17 ± 4 years, range 6–37, 38% female), average test times at baseline were 41.2 ± 11.2 s. The group included 280 youth, 357 collegiate and 44 professional athletes; the most common sports were ice hockey (23%), soccer (17%) and football (11%). Age was a predictor of MULES test times, with longer times noted for younger participants ($P < .001$, linear regression). Consistent with other timed performance measures, significant learning effects were noted for the MULES during baseline testing with trial 1 test times (mean 49.2 ± 13.1 s) exceeding those for trial 2 (mean 41.3 ± 11.2 s, $P < .0001$, paired *t*-test). Among 17 athletes with concussion during the sports seasons captured to date (age 18 ± 3 years), all showed increases (worsening) of MULES time scores from pre-season baseline (median increase 11.2 s, range 0.6–164.2, $P = .0003$, Wilcoxon signed-rank test). The Symptom Severity Score from the SCAT5 Symptom Evaluation likewise worsened from pre-season baseline following injury among participants with concussion ($P = .002$).

Conclusions: Concussed athletes demonstrate worsening performance on the MULES test compared to their baseline time scores. This test samples a wide network of brain pathways and complements other vision-based measures for sideline concussion assessment. The MULES test demonstrates capacity to identify athletes with sports-related concussion.

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1. Introduction

Tests of rapid automatized naming (RAN), including rapid picture naming, have been in use for > 50 years to capture aspects of vision, cognition and language function [1–11]. Measures that involved rapid naming of color photos were described by Reusch and Wells [2] in a 1940's guide, the *Mental Examiner's Handbook*. A picture naming test that incorporated 50 color photographs was developed in the late 1960's by Geschwind [3,4]. The term rapid automatized naming (RAN) was introduced in 1974 for studies of rapid color, letter and number naming by normal children [5]. The RAN literature has demonstrated that subjects with and without dyslexia (reading deficits) require increased time to name objects compared to symbols [3–9].

The Mobile Universal Lexicon Evaluation System (MULES), a new test of rapid naming of photographic images in context, aims to examine the brain's visual pathways and neural networks by testing color perception, object identification, conceptual representation, phonology and articulation [10–16]. Our team's recent publications on the MULES suggested that the test is feasibly administered to athletes and patients across the age spectrum, and that the MULES showed preliminary evidence of capacity to identify athletes with sports-related concussion [14] as well as to demonstrate abnormalities in people with multiple sclerosis (MS) [15]. This was particularly true for a revised version of the MULES that is a laminated 8.5″ × 11″ double-sided version that the participant flips vertically from Side 1 to Side 2 during the timed testing protocol (Fig. 1) [14].

The purpose of this study was to quantify the magnitudes and directions of changes in MULES test time scores for youth, collegiate and professional athletes from pre-season baseline testing to post-concussion sideline assessment. We also determined the relation of MULES test time scores at baseline to those for Sport Concussion Assessment Tool (SCAT5) sideline tests at pre-season baseline and post-concussion, including the Symptom Severity Scale score from the Symptom Evaluation.

2. Subjects and methods

2.1. Study participants

A convenience sample of athletes from regional youth, collegiate and professional leagues underwent pre-season baseline (pre-injury) concussion testing. Testing included components of the Sport Concussion Assessment Tool (SCAT5, child SCAT3 for those under 13 years old) [13,17] and the MULES. Analyses for this study were focused on the Symptom Severity Score from the SCAT5 Symptom Evaluation. Athletes who sustained a concussion during athletic play or practice were tested on the sidelines as soon as was feasible using the MULES and SCAT5 components. Time scores for post-concussion tests were compared to those of baseline test times. Written informed consent and age-appropriate assent were obtained from each participant and their parent/ guardian; the Institutional Review Board (IRB) at New York University School of Medicine approved all study protocols.

2.2. Testing procedures

Portions of the SCAT5 (including Symptom Evaluation) were selected to be administered for both the baseline and post-concussion testing using standard procedures. The MULES test consists of 54 original photographs of fruits, objects, and animals with 26 pictures printed on each side a laminated 8 × 11-inch sheet of paper (Fig. 1) [12,14]. Participants were asked to name the pictures in conventional reading order as quickly as possible. The MULES time score was determined as the time required for the participant to name all of the pictures on both sides of the laminated sheet (the subject flips the sheet with the timer running). The test sheet is held at arm's length in a relaxed manner determined by the examiner. During pre-season baseline test administration, the MULES was administered twice, with the baseline value recorded as the best of the two trials. During post-concussion testing, the MULES was administered again. Tests were administered by trained study personnel at all the sites for pre-season baseline and by athletic trainers or designated parent testers for athletes who sustained a concussion.

2.3. Statistical analyses

Data were analyzed using Stata SE 15.1 (StataCorp, College Station, TX). Within-participant differences between MULES test trials (learning effects) in terms of time scores were analyzed for baseline measurements using paired *t*-tests. Linear regression models were used to examine the relation of age to MULES test time scores. For analyses of the 17 athletes who developed concussion, non-parametric tests for paired data (Wilcoxon signed-rank tests) were used to compare pre-season baseline vs. post-concussion MULES scores within participants.

3. Results

Among 681 athletes, age 17 ± 4 years, range 6–37, 38% female), the average MULES test time at baseline (best of two trials) was 41.2 ± 11.3 (Table 1). There were significant reductions in time score between trials 1 and 2, consistent with learning effects that are inherent in performance measures [18] ($P < .0001$, paired *t*-test; Fig. 2). Age was a predictor of pre-season baseline MULES test times, with longer times noted for younger participants ($P < .001$, linear regression).

Among 17 athletes with concussion to date (age 18 ± 3 years), all showed significant worsening of MULES scores from pre-season baseline to post-concussion testing (median 11.2 s, range 0.6–164.2, $P = .0003$, Wilcoxon signed-rank test; Table 1) (Fig. 3). The Symptom Severity Scale of the SCAT5 Symptom Evaluation likewise demonstrated significant increases (worsening) from pre-season baseline for all athletes with concussion ($n = 17$, $P = .002$, Table 1). Among athletes who completed both the MULES and the Symptom Evaluation, similar increases in symptom severity were observed following concussion ($n = 15$, $P = .002$, Wilcoxon signed-rank test).

4. Discussion

The MULES test of rapid picture naming identifies performance decrements from pre-season baseline when tested on the sideline among athletes with concussion across age groups from youth through collegiate and professional leagues. As demonstrated in previous studies of the MULES, time scores decrease with age among youth athletes, supporting the use of pre-season baseline measurements in these age groups [12,14]. Increases (worsening) in MULES times occurred in conjunction with worsening of Symptom Severity Scores from the SCAT5, supporting the concept that prolonged MULES scores are associated with self-reported dysfunction following concussion.

The MULES in its current form has been recently and successfully converted to a more compact 8.5 × 11-inch two-sided laminated version [12,14]. Data from a recent study confirmed excellent agreement between the newer laminated MULES and its larger predecessor with respect to pre-season and post-concussion measurements [14]. Based on feedback from the sports parents, athletic trainers and physicians involved in the ongoing research studies of the MULES, the smaller and laminated profile renders the test more practical for the sideline and clinical settings. For example, the smaller version fits in a briefcase or athletic bag. The present study, which incorporated the newest MULES version, confirmed a high degree of sensitivity in this heterogeneous group of athletes. Since concussion remains a clinical diagnosis, sensitive performance tests and other markers are needed, particularly when the presence of concussion is not certain [13].

Younger athletes in our cohort had greater baseline time scores for both the current version and the previous larger version of the MULES

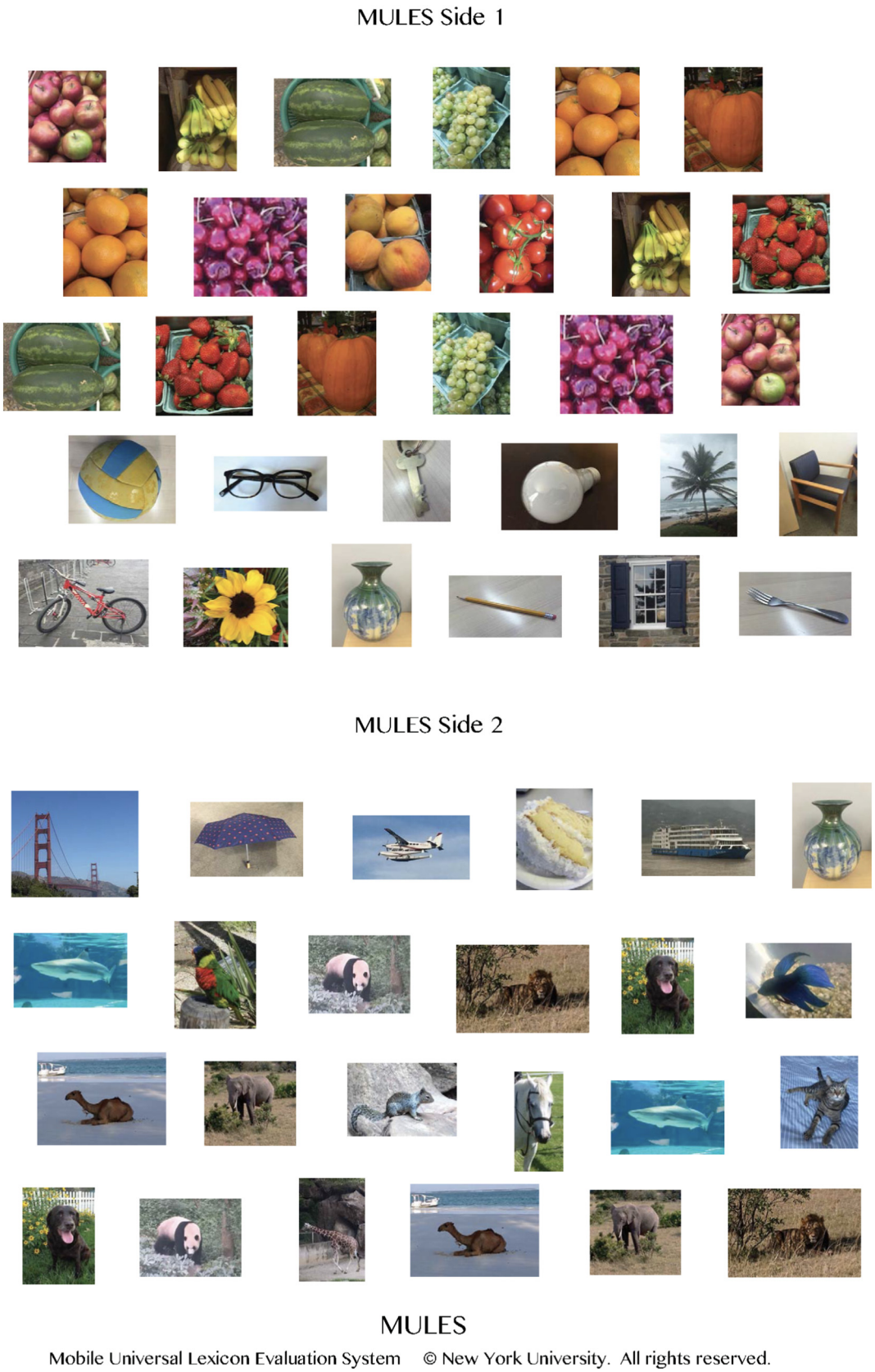

Fig. 1. The Mobile Universal Lexicon Evaluation System (MULES) test of rapid picture naming, as examined in the present manuscript (MULES Test © New York University, text and photographs, registration number TXu002026665, all rights reserved). The MULES is printed two-sided on an 8.5 × 11-inch sheet of paper and includes 54 original photographs of fruits, objects and animals. The participant names the pictures orally from left to right as rapidly as possible. The score is the time in seconds required to name all pictures (participant flips the laminated sheet of paper during test timing). Figure adapted from [14].

Table 1
Concussion test scores for pre-season baseline and post-concussion for athlete participants.

	Age in years at baseline, mean ± SD (range)	Pre-season baseline scores, mean ± SD (range)	Post-concussion scores, mean ± SD (range)	Differences between post-concussion and baseline scores, median (range)
Mobile Universal Lexicon Evaluation System (MULES)				
Pre-season baseline testing, total cohort (n = 681)	17 ± 4 (6–37)	41.2 ± 11.3 (22.2–107.4)	–	–
Athletes with concussion tested with MULES (n = 17)	18 ± 3 (11 − 21)	40.0 ± 6.6 (29.5–50.8)	59.6 ± 37.7 (30.1–199.7) [a]	11.2 (0.6–164.2)
Symptom Severity Scale				
Pre-season baseline testing, total cohort (n = 572)	18 ± 6 (6–37)	4.4 ± 7.2 (0–54)	–	–
Athletes with concussion tested with Symptom Severity Scale (n = 17)	18 ± 3 (11–21)	6.5 ± 11.8 (0–41)	25.3 ± 26.0 (0–76) [b]	12 (−3–72)

Comparisons of pre-season baseline vs. post-concussion test times for athletes with concussion, Wilcoxon signed-rank tests.
[a] P = .0003.
[b] P = .002.

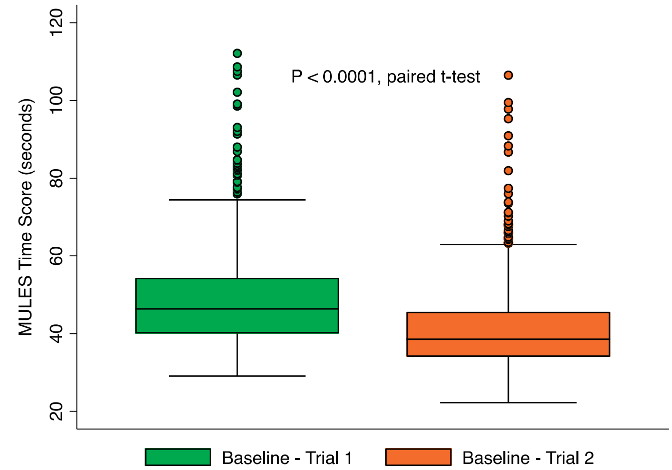

Fig. 2. Box plots demonstrating average MULES time scores in seconds for trials 1 and 2 at pre-season baseline testing (n = 681). Significant decreases in MULES time scores between trials 1 and 2 (P < .0001, paired t-test) are consistent with learning effects that are characteristic of timed performance measures. The lines in the box represent the medians, and the boxes delineate the interquartile range (25th to 75th percentiles). Whiskers represent the range of observations minus outliers.

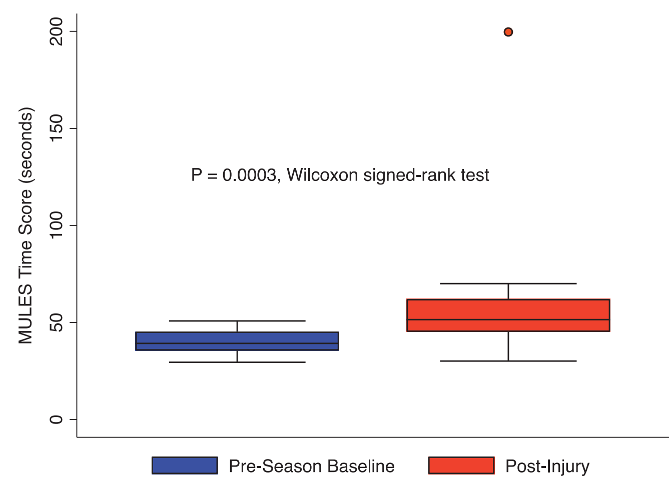

Fig. 3. Box plots demonstrating average pre-season baseline vs. post-concussion MULES test scores in seconds for athletes with concussion (n = 17). There was a significant increase (worsening) of MULES time scores from pre-season baseline to post-concussion (P = .0003, Wilcoxon signed-rank test) and all concussed athletes demonstrated some degree of worsening. The lines in the box represent the medians, and the boxes delineate the interquartile range (25th to 75th percentiles). Whiskers represent the range of observations minus outliers.

[12,14]. These findings are expected developmentally for a vision-based performance measure and may be attributable to the ongoing development of the frontal lobes and the temporal-parietal regions responsible for object categorization [19–22]. The prefrontal cortex is one of the last structures to develop and subserves the executive functions of inhibitory control, temporal integration, preparatory setup for saccades and working memory. White matter within these areas increases in young participants into adulthood; the cortico-cortical tracts reach a full state of myelination in the 20's [23–25]. These factors likely lead to age-dependence of the performance of rapid-picture naming tasks on age, reflecting developmental trajectory. The observed peak in baseline scores in late adolescence corresponds to documented performance peaks in working memory, processing speed and response suppression documented in investigations of cognitive development among adolescents [26].

The results of our study to date show consistent worsening of MULES scores from pre-season baseline among a small cohort of athletes with concussion. At least half of the MULES scores worsened by > 10 s from pre-season baseline (Table 1). Since learning effects and improvement are typically noted between testing sessions for performance measures, any worsening of time scores from pre-season baseline is considered consistent with injury. Previous studies have demonstrated the need for a composite of tests to identify all athletes with concussion [27]. Since approximately 50% of the brain's pathways are dedicated to vision, the addition of a rapid picture naming task to tests of rapid number naming may increase the capacity for sideline vision-based tests to identify athletes with concussion.

The MULES test is additive to the SCAT5 since the MULES provides a visual assessment. This augments the concussion testing battery provided by the SCAT5, which captures symptoms, cognitive function and balance. Ongoing and future studies will continue to determine the relation of MULES time scores to cognition and balance. We also plan to examine the time recovery of the MULES test post injury on the sideline and in the clinic and to look at scores of controls over time. The association of new symptoms with a delay in MULES times in this cohort of concussed athletes supports a low rate of false positivity. If feasible, our team will ask athletic trainers to simultaneously test non-concussed control participants in a future study to determine changes from baseline in this group.

Functional MRI protocols that incorporate MULES testing may also identify patterns of network activation during both pre- and post-concussion measurements. A functional MRI investigation of 15 university students found that object-based RAN tasks preferentially activated the bilateral fusiform gyri and area V4; these areas are involved in form recognition, especially for faces [16].

With imaging studies employing rapid automatic naming tasks, we may gain insight into the pathophysiology of concussions or other neurologic disorders with visual system impairments. The MULES test requires the identification of complex photographs and has been able to distinguish patients with multiple sclerosis (MS) from disease-free control participants [15]. Studies are underway to examine the role for MULES in distinguishing patients with a variety of neurodegenerative disorders, including Parkinson's and Alzheimer's diseases.

The MULES test requires a variety of visual processing domains as well as saccades and convergence, two of the most commonly impaired eye movements following concussion [10,11]. Assessment of eye movements clinically requires proper examination technique and a determination of abnormal findings both at baseline and at the time of injury. The detection of such eye movement abnormalities can be challenging and usually requires expertise and experience. A visual outcome measure like the MULES does not substitute for a complete eye movement evaluation, but it does provide a visual assessment that is easy to perform and it captures many of the key eye movement abnormalities that follow concussion. This is especially noteworthy since most concussions occur in the early adolescent age group and in communities where professional assessment is not always possible [28]. Thus, a performance test such as the MULES can help with assessment on the sidelines and to determine whether an athlete should be removed from play and referred to a trained medical professional for evaluation. In our experience, such tools such as the SCAT5 and MULES test can be invaluable to such communities and can provide an incentive to neighborhood athletic groups to organize their concussion protocols [28]. Since the MULES test integrates widely distributed cortical networks, applicability of the MULES as an assessment tool will likely extend to a variety of neurological and neurodegenerative disorders beyond concussion.

Disclosure statements

The authors have no financial interests.

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