Are Reliable Change (RC) calculations appropriate for determining the extent of cognitive change in concussed athletes?

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Reliable Change (RC) analyses are a group of statistical techniques that are used in many areas of medicine to help determine when an individual’s performance on a neuropsychological test has changed from a previous assessment\(^1\) with the same test. Recently, in sports concussion, numerous authors have advocated the application of the RC analyses to neuropsychological test data collected at baseline (pre-season) and after a concussion\(^2-3\). These authors have stated that the results of RC analyses provide the best means for guiding decisions about whether or not true change in cognitive function has occurred following a concussion, and can therefore assist the return-to-play decision making process. Although we support the use of RC techniques to guide decisions about concussion, we have concerns about the statistical computation and interpretation of various RC indices.

Reliable change techniques were first described by Jacobson and Traux\(^1\), and were designed to aid decision making about the significance of cognitive changes in individuals in whom an injury or intervention had taken place. These and subsequent authors\(^4-5\), proposed that the most efficient way of determining whether an individual’s score on a specific cognitive measure had changed was to express the magnitude of change (i.e., a change score) as a function of the normal variation found for that measure. Normal variation in performance on the cognitive measure was estimated from a group of similar individuals in whom no injury or intervention had occurred. Mathematically, the individual’s change in performance is expressed in the numerator and the
normal variation in performance on that measure is expressed in the
denominator (Figure 1).

Clinicians, neuropsychologists and statisticians working with RC techniques
soon realised that ‘true’ changes in individuals’ test scores could be obscured
by performance changes due to practice (i.e., prior exposure to a test leads to
improved performance on a subsequent assessment) and also by statistical
phenomena such as the reliability of the test and the related
regression to the mean. This has led to the description and application of
several variants of the basic RC index. These variants have sought to provide
more accurate guidance to decisions about pre-to-post event change by
incorporating corrections for practice effects, test reliability and regression to
the mean. The outcome of RC analyses may be interpreted statistically as a
z-score, with changes greater than 1.96 indicating that true change has
occurred. In sport medicine settings, where the focus is detecting decline in
performance following a concussion (i.e., a one-tailed hypothesis), an RC of
less than –1.65 indicates true decline has occurred. One advantage of RC
statistics is therefore that they can be applied immediately to individual level
data, and therefore interpreted on an individual basis. This makes them
applicable to clinical situations such as in sports concussion.

Reliable change analyses were designed in accordance with conventional
models of neuropsychological assessment. That is, to determine whether the
change observed in the individual is true by comparing it to change that occurs normally in some matched normative data set. The problem with currently applied RC calculations is that the normal amount of variability in change over time within individuals is estimated on the basis of differences between individuals assessed at a single time point! There is no reason to believe that variation between individuals at one time point accurately represents the variation within individuals between two time points. A related problem with current RC analyses is that the normal variation represented in the denominator is termed the standard error of the difference (SE_{\text{diff}})^1, despite the fact that it is computationally the standard deviation of the individual scores at one point in time. A true estimate of change requires the standard deviation of difference scores (SD_{\text{diff}}) in the denominator.

In sports medicine, we are in the fortunate position of having many healthy young individuals enrolled in longitudinal studies of concussion, and relatively few neuropsychological measures administered in these studies. There should be no reason why the normal change in performance over time within individuals cannot be determined directly from such control group data rather than using inappropriate estimates of variation. In fact, many researchers have obtained serial data for inclusion in RC calculations as corrections for the effects of practice observed in normal populations, including some authors working in sports concussion\textsuperscript{2-3}. Although such serially acquired data is adequate for directly estimating the SD_{\text{diff}} from a normal sample, these authors have continued to employ the ‘estimated’ SD_{\text{diff}} rather than directly calculating the SD_{\text{diff}} for inclusion in the RC calculation.
Some minor alterations to previous RC calculations produces a RC calculation that is mathematically and theoretically correct, yet retains all the virtues of previously proposed RC calculation (Figure 2). That is, this RC technique can be interpreted as a z-score, with a change of greater than -1.65 indicating significant decline from baseline using a one-tailed hypothesis. Such RC scores may also be interpreted as ‘effect size’ calculations, very similar to Cohen’s d scores as described by Zakzanis. Our research group applies this calculation (described in Figure 2) to neuropsychological test data gained in concussed athletes in many sports worldwide, and in many other medical applications where issues of change in an individual’s cognitive status are pertinent. Corrections for practice effects and other confounding variables may also be included in this calculation as per current RC techniques.

Summary

Reliable change analyses have the potential to inform return-to-play decision making in sports concussion settings, when applied to serially acquired neuropsychological test data. However, to be applied appropriately, such calculations should endeavor to directly assess the magnitude of change in an individual’s test score relative to change in a control group assessed at similar
test-retest intervals. Previously described RC calculations do not meet this basic criterion, despite such control data being available.
References


