# 'Sea legs': sharpened Romberg test after three days on a live-aboard dive boat

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**Key words**
Ear barotrauma, decompression illness, decompression sickness, sharpened Romberg test, motion sickness, postural control

**Abstract**
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**Introduction:** The sharpened Romberg test (SRT) is commonly used by diving and hyperbaric physicians as an indicator of neurological decompression illness (DCI). People who spend a prolonged time on a boat at sea experience impairment in their balance on returning to shore, a condition known as *mal de debarquement* ('sea legs'). This conditioning of the vestibular system to the rocking motion of a boat at sea may impact on the utility of the SRT in assessing a diver with potential DCI after a live-aboard dive trip.

**Aim:** To assess the impact 'sea legs' has on the SRT after three days on a live-aboard dive trip.

**Methods:** Thirty-nine staff and passengers of a three-day, live-aboard dive trip performed a SRT before and after their journey, with assessment of potential variables, including middle ear barotrauma, alcohol consumption, sea-sickness and occult DCI.

**Results:** There was no statistically significant impact on SRT performance, with 100% completion pre-trip and 35 out of 36 divers (97.2%) post-trip. There were trends towards more attempts being required and time needed for successful SRT post-trip, but these were not statistically significant. There was a small, but noteworthy incidence of middle-ear barotrauma, with seven people affected pre-trip, and 13 post-trip. There was a higher incidence in student divers. Middle-ear barotrauma did not appear to have a direct impact on SRT performance.

**Conclusion:** There was no significant impact on SRT performance resulting from 'sea legs' after three days at sea. Recreational divers, especially dive students, have a substantial incidence of mild middle ear barotrauma.

## Introduction

The sharpened Romberg test (SRT) is commonly used by physicians as an indicator of neurological decompression illness (DCI).[1,2] People who spend a prolonged time on a boat at sea often experience impairment in their balance on returning to shore, a disorder known as *mal de debarquement* or 'sea legs'. This conditioning to the rocking motion of a boat at sea may impact on the utility of the SRT in assessing a diver with potential DCI after a live-aboard dive trip.

### SHARPENED ROMBERG TEST

The Romberg test (RT), from which the SRT is derived, was first described by Dr Moritz Romberg in 1846 as an indicator of tabes dorsalis in patients with neurosyphilis.[3] This reflected the loss of lower limb proprioception through destruction of the dorsal columns of the spinal cord. Modifications of the RT were first described by Edmond Barbey in 1944, with Alfred Fregly introducing the 'sharpened' RT in 1966 with his research into vestibular disease. 'Sharpening' of the RT permits assessment of the cerebellum and vestibular apparatus, as well as lower limb proprioception.[4–7] Its use has since expanded, and the SRT was introduced into diving medicine by Dr Carl Edmonds in 1974.[5]

In hyperbaric and diving medicine, the SRT is commonly used in the objective assessment of neurological DCI, and as a marker of recovery following treatment with hyperbaric oxygen.[2,5,8,9] Research has shown the SRT has a sensitivity between 46–49% and a specificity of around 95% for DCI, and is "*a useful marker of decompression illness*", especially in "*a patient where the disease process was in question*".[5,9] Additionally, dive medicals in Australia and Europe include a baseline assessment of the SRT.[7,10–12] Known independent confounders of the SRT include alcohol intoxication, advancing age, and female gender.[4,6,13–15] Any 'learning effect' present is minimal and generally not clinically relevant.[5,6,16]

### MAL DE DEBARQUEMENT

*Mal de debarquement*, or 'sea legs', is the sensation of a persistent rocking or swaying motion, with associated unsteadiness and dysequilibrium, experienced by people who spend time on a boat at sea. It occurs upon returning to shore and is usually transient, lasting hours to days, and resolving spontaneously.[17–20] The symptoms of 'sea legs' are believed to be secondary to central nervous system adaptation to the rocking motion of a boat at sea, but can also occur after rail, air and car travel.[18,19] It is unclear how long it takes for 'sea legs' to develop, with as little as five hours at sea producing symptoms.[17] However, most reports of 'sea legs' document it occuring after a prolonged time at sea.[17–20] Nearly everyone adapts to the rocking motion of a boat within two to three days, as seen in the resolution of sea sickness.[2]

Single-day dive-boat trips are common, but the SRT after such trips is not affected.[5] Live-aboard trips permit divers to stay out at dive sites for a number of days, commonly 2–7 days, but increases the likelihood and severity of 'sea legs'.[1] This might, in turn, independently affect SRT performance. Our study aimed to determine whether 'sea legs' experienced by divers and snorkellers spending three days on a live-aboard dive boat results in compromise of their SRT. The null hypothesis was that spending three days on a live-aboard dive boat would not impair subjects' SRT performance.

## Methods

Ethics approval for this study was granted by the Human Research Ethics Committee of Townsville Health Service District. Thirty-nine people participating in a three-day live-aboard dive trip, including five crew members and two of the researchers (CG and KC), were enrolled into the study, and underwent a SRT prior to boarding, and within one hour of disembarking. Seventeen participants were completing their Professional Association of Diving Instructors (PADI) 'Open Water Diver' certificate at the time of the study, and had finished two days of pool work prior to their initial assessments. All participants were given a study information sheet and informed consent was obtained. All collected data were de-identified and recorded onto a pre-formatted worksheet. This information was, in turn, entered onto a Microsoft Excel spreadsheet, and analysed using SPSS Version 17.0.

The SRT was performed on a flat, hard surface, barefoot or in hard-soled shoes, with one foot in front of the other. Subjects could decide for themselves which foot they placed in front. Arms were then crossed in front of the body, with the palms rested on the contralateral shoulder. Once settled, the subject was asked to close their eyes and keep their balance for 60 seconds (Figure 1). Each attempt was timed using a stop watch, which was stopped if the subject opened their eyes, shifted their feet, moved their arms, or fell over. The time of each attempt was recorded, and subjects were given four attempts to reach 60 seconds, adhering to Fregly's original description of the test and allowing comparison to other SRT research.[4,5,9] If they remained steady for 60 seconds, subsequent attempts were not required.

Subjects also underwent otoscopic examination of both tympanic membranes using a Welch Allyn Diagnostic Otoscope before and after the trip, with any signs of middle-ear barotrauma (MEBT) graded by two researchers (CG and KC) using the Edmonds classification system:[2]
Grade 0 – Symptoms without signs
Grade I – Injection of the tympanic membrane (TM)
Grade II – Injection, plus slight haemorrhage in the TM

**Figure 1**
**The stance to be adopted by a subject performing the sharpened Romberg test[4,5,9]**

Grade III – Gross haemorrhage within the TM
Grade IV – Free blood in the middle ear
Grade V – Perforation of the TM.

Signs of otitis externa were also documented. A digital image was kept of the post-trip findings, recorded with a Welch Allyn Digital MacroView Otoscope (Welch Allyn Australia, Radylmere NSW), to enable external validation by hyperbaric physicians blinded to the subjects' SRT results.

Basic demographic data were collected on each participant, as well as the use of any medications and incidences of sea-sickness. The dive profiles (maximum depth, underwater time and surface interval) of each participant were recorded by obtaining copies of the dive logs completed by the dive supervisors. Notably, there were two non-divers on the trip, who snorkelled a number of times. A record of alcoholic drinks consumed by passengers and crew was to be noted, but, because of changes in the company's alcohol licence, this was not possible. Timing of the SRT assessments ensured no subject was intoxicated whilst being tested.

### STATISTICAL ANALYSIS

Our *a priori* plan for primary analysis was to use McNemar's Chi-square to evaluate the proportion of subjects passing SRT pre- and post-live aboard while accounting for the paired nature of the data, as well as comparing the exact 95% confidence intervals. The number of attempts required to achieve success pre- and post-live aboard were compared using the Wilcoxon Signed Rank Test, and differences in the cumulative time score for the SRT were compared using a paired t-test. The cumulative time score is calculated from the sum of the times of the four attempts, with a maximum score of 240 seconds. If a subject maintains the SRT stance for 60 seconds, subsequent attempts are allocated 60 seconds and not performed. For all analyses, an alpha value of 0.05 was used to establish statistical significance.

## Results

SRT

All 39 people on the boat were enrolled in the study; 22 (56.4%) male and 17 (43.6%) female. Ages ranged from 18 to 55 years, with a mean age of 26.4 +/- 7.1 years. The participants in the study were demographically similar to divers treated at The Townsville Hospital Hyperbaric Medicine Unit in the past three years ($n$ = 38; mean age 31 +/- 8.7 years, range 14–52, 54.5% male).

All 39 subjects successfully completed the pre-trip SRT; 30 on the first attempt, six on the second attempt, two on the third attempt and one on the fourth attempt. The median number of attempts required to achieve success was 1 (interquartile range: 1 – 1), and the average cumulative time score was 226.5 +/- 10.0 seconds.

Two subjects departed immediately after returning to shore and were thus lost to follow-up. One participant declined to perform subsequent attempts after not obtaining 60 seconds on their first post-trip SRT attempt and, therefore, was also considered as lost to follow-up. Of the 36 subjects completing the post-trip assessment, 35 (97.2%; 95% CI 85.5% to 99.9%) were successful; 25 on the first attempt, five on the second attempt, three on the third attempt and two on the fourth attempt. The median number of attempts required to achieve success was 1 (IQR: 1 – 2), with an average cumulative time score of 217 ± 14.0 seconds.

The absence of any failures at baseline precluded analysis using McNemar's Chi-square; the confidence intervals around the proportions for successful SRT pre- and post-trip, however, do overlap. This remains true even when the three subjects lost to follow-up are allocated as 'failures' (35/39 = 89.7%; 95% CI 75.8, 97.1).

There was no significant difference in the number of attempts required to achieve success pre-trip versus post-trip (Wilcoxon Signed Rank Test, $P$ = 0.563). When conservatively allocating the one subject who failed SRT and the three subjects lost to follow-up as requiring five attempts, there remained no significant difference, although a trend towards more attempts in post-trip SRT became more apparent (Wilcoxon Signed Rank Test, $P$ = 0.064) (Figure 2). This general trend of poorer performance is also seen in the cumulative time score, with a difference of 9.4 seconds, but again this was not of statistical significance ($P$ = 0.358) (Figure 3). Removing data for the two subjects who only snorkelled had no impact on the results.

OTOSCOPY

Seven of the 17 'Open Water' students had otoscopic

**Figure 2**
**Pre- and post-trip cumulative percentage of successful SRT performance with each attempt ($P$ = 0.563); allocating those lost to follow-up as requiring five attempts post-trip, the difference was not statistically significant ($P$ = 0.064)**

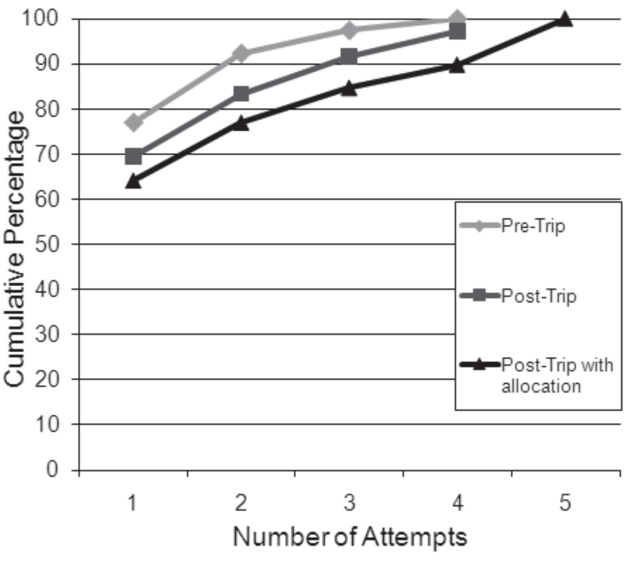



**Figure 3**
**The 'cumulative time score' for SRT performance pre- and post-trip with 95% confidence intervals; difference 9.4 seconds ($P$ = 0.358)**

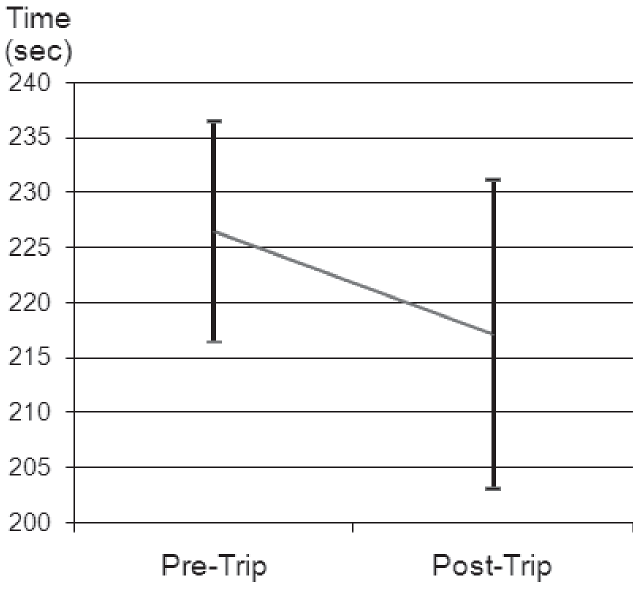
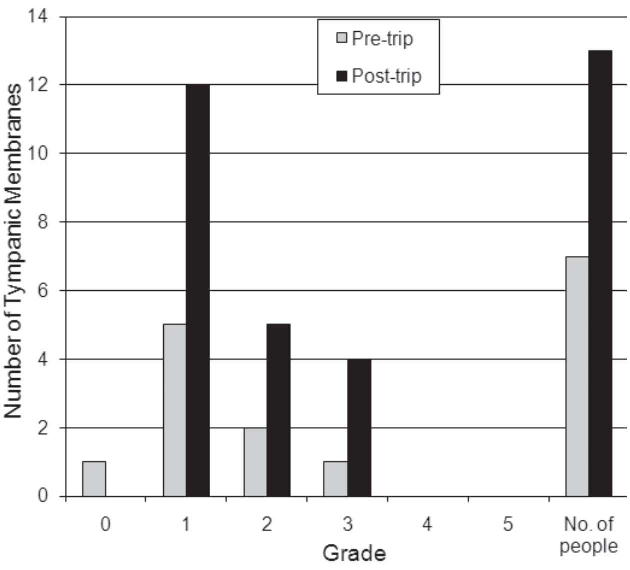


**Figure 4**
**The incidence and grade of middle-ear barotrauma pre- and post-trip, graded using the Edmond's classification system[2]**




evidence of MEBT prior to the live-aboard trip (41.2%), resulting from pool training dives. Most had Grade I changes ($n$ = 5), with the worst being Grade III ($n$ = 1), affecting nine tympanic membranes. None of the certified divers ($n$ = 22) had MEBT prior to the trip, giving an overall pre-trip MEBT incidence of 17.9%. After completion of the trip, thirteen participants (33%) had MEBT, a significant increase ($P$ = 0.002), with 21 tympanic membranes affected. Of the 32 with no MEBT prior to the trip, seven had developed MEBT (21.9%). Again, most only had Grade I changes ($n$ = 12), but two participants had Grade III changes involving both tympanic membranes (Figure 4).

MEBT was recorded as an indicator of possible inner ear barotrauma, a known confounder of SRT performance. Despite a statistically significant increase in the incidence of MEBT after the trip, there appeared to be no direct link between it and SRT performance. The one subject who failed the post-trip SRT assessment had bilateral Grade II MEBT, but the two subjects with more severe injuries (bilateral Grade III) passed their post-trip SRT on the first attempt. Also, the two subjects who required four attempts to pass the post-trip SRT (i.e., 'nearly failed') had normal middle ear otoscopy. As any MEBT present did not affect the SRT, the barotrauma grades were not externally validated.

DIVE PROFILES

It was not possible to correlate subjects' dive profiles with SRT performance because we did not have access to subjects' dive computers. Depth and time information was available; however, the divers performed multi-level dives. When compared to DCIEM and PADI tables, some of the divers may have missed recommended decompression stops; however, without the raw data from computers we were unable to undertake any meaningful analysis. All divers, except one who only made one attempt, passed the SRT after the trip, and no divers complained of symptoms that were consistent with DCI.

SEA CONDITIONS

Wind and sea conditions were regularly estimated by the company's dive supervisor and recorded on the dive logs. Wind speeds ranged from calm to 15–20 knots, with most records (9 of 11) noting speeds over 10 knots. Sea conditions ranged from 'calm' to 'choppy' over the trip, with it being 'choppy' most of the time (7 of 11 records).

## Discussion

The SRT is routinely used by physicians in the assessment of divers with potential neurological DCI, and in monitoring the response to treatment. The persistent swaying and rocking sensation of 'sea legs' could be expected to produce an abnormal SRT. Lee found a half-day, open-water boat trip had no effect on SRT performance.[5] Our aim was to evaluate whether 'sea legs' produced by a longer period at sea would affect SRT performance. The 39 subjects spent over 60 hours on a boat in open waters. All 39 successfully completed the SRT prior to the trip, and 35 of 36 subjects (97.2%) successfully performed the post-trip SRT, three subjects being lost to follow-up. This difference in pre- and post-trip SRT success rates was not statistically significant, even if those lost to follow-up were labelled as having failed. In an attempt to unmask subtle changes in SRT performance, we examined the number attempts required and the cumulative time score. Neither of these measures showed a statistically significant difference in performance.

Only two previous studies into the utility of the SRT in diving medicine have been published. The first paper prospectively assessed SRT performance in 60 control subjects, and retrospectively reviewed 35 cases of DCI.[9] Nearly half of the divers with DCI had a markedly abnormal SRT performance (less than 30 seconds). The rest had a near-normal performance, with times comparable to the control group. The majority of those with an abnormal SRT prior to treatment had normal SRT performance following recompression therapy. Fitzgerald deduced "*the SRT could be used as a 'marker' for DCI*".[9]

In a similar study, SRT performance was assessed prospectively in a control group, and retrospectively in 50 cases of DCI.[5] This showed that a single-day boat-diving trip did not adversely impact on SRT performance, and that roughly half of the divers with DCI had a markedly abnormal SRT performance (less than 35 seconds). All of the DCI cases improved to a normal SRT after treatment, supporting the earlier findings. Lee concluded that "*the sharpened Romberg test is a useful marker of decompression illness*" and is "*resistant to several potentially confounding factors*" such as *"post-dive fatigue, decompression stress, vestibular disturbance resulting from the swaying motion of a dive boat and improvements due to practice or learning effect*".[5]

Our study looked exclusively at what Lee called *"vestibular disturbance"*, more commonly known as 'sea legs'. We hypothesised that spending three days at sea on a boat would amplify the development of sea legs, resulting in SRT failure. Our hypothesis was disproved; the SRT was not affected.

'Sea legs' is a diagnosis of exclusion, with no single diagnostic test. There is little consensus about the underlying pathogenesis of the condition, with traditional theories generally revolving around the concept of neuroplasticity of the vestibular apparatus. However, published reports of 'sea legs' commonly document normal examination, specifically with normal or equivocal vestibular testing.[17,18,20] Newer theories still involve the vestibular apparatus, but focus on neuroplasticity of higher centres in the cerebral cortex and hippocampus. These may then provide ongoing stimulation of the vestibular apparatus, and generate the ongoing sensation of swaying.[17,18,20]

The SRT assesses the cerebellum, the vestibular apparatus and lower limb proprioception. The failure of our hypothesis supports earlier research into 'sea legs' and the lack of evidence of abnormal vestibular function. If the pathogenesis of 'sea legs' truly lies 'higher' than the vestibular apparatus, then the SRT would not be affected, as seen with our results.

We attempted to account for, and record the presence of, potential confounders of SRT performance, including alcohol intoxication, provocative dives, and inner ear barotrauma (IEBT). None of the subjects were under the influence of alcohol at the time of the SRT assessment, controlled by timing of the testing. It was not possible to draw any conclusions from the dive profiles because computer dive records were not available.

The mechanism between IEBT and poor SRT performance is clear and logical, but there is no published research examining a direct correlation between MEBT per se and the SRT. Analysis of our limited data did not reveal any obvious link between MEBT and SRT performance, but further directed research into this should be performed before a solid conclusion can be made.

Our study has a number of limitations. Firstly, the sample size was constrained by the capacity of the dive boat; however a *post hoc* power analysis reveals the study to be adequately powered to statistically detect small differences in the SRT success rate. With either 36 or 39 subjects, the power to detect a decrease in SRT success from 99.9% to 96.0% exceeded 0.80. Thus, it is unlikely that this study failed to identify any clinically meaningful change in SRT performance.

Secondly, our hypothesis was based on the premise that spending three days at sea would result in the subject developing 'sea legs'. Being a diagnosis of exclusion, we were reliant on subjective descriptions of symptoms consistent with 'sea legs'. The majority of subjects stated they felt unsteady during their post-trip SRT, "*like* [they were] *back on the boat*", and almost certainly had developed 'sea legs'. 'Sea legs' severity is likely to increase with even more prolonged durations at sea and/or more severe sea conditions, and may still influence SRT performance. Correlation with varying sea conditions may also be of importance.

## Conclusions

The effects of 'sea legs' on people spending three days on a live-aboard dive trip does not impair their ability to perform a SRT. Therefore, in a patient with suspected DCI, who has spent some days at sea, SRT failure should not be attributed to 'sea legs' and should be considered a confirmatory marker of DCI.

MEBT was common. Further studies of the SRT in divers who remain at sea for many days is warranted, and any correlation between MEBT and SRT performance should be examined.

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