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Editor
Abstract
Research in musicians’ health in the last 30 years reveals that anywhere from 37 percent to 87 percent of both adults and students suffer pain related to the practice of their craft; nearly as often as athletes do. ASTA was one of the first professional organizations to recognize the problem. But how much do we really know about performance injuries and their prevention? Musicians, music educators, and movement and medical scientists have all investigated these issues. String researchers have been particularly active in studying the biomechanics of playing and in testing preventions and interventions, and they are uniquely qualified to contribute to understanding in these and other aspects of music wellness.

Keywords
wellness, musician health, performance injury, higher education, research, string pedagogy

Research in musicians’ health in the last 30 years reveals that anywhere from 37 percent to 87 percent of both adults and students suffer pain related to the practice of their craft; nearly as often as athletes do. The American String Teachers Association (ASTA) was one of the first professional organizations to recognize the problem, holding a conference on musicians’ injuries and performance anxiety in 1984 that resulted in Sforzando (Mischakoff, 1985), one of the first publications on the topic. The importance of these issues has become more visible within the music education community, broadly speaking, in the

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2 This Forum article is based on an invited presentation by the author at the 2012 ASTA National Conference in Atlanta, Georgia.

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last 20 years. For example, two chapters of *The New Handbook of Research in Music Education* (Colwell & Richardson, 2002) are devoted to musical health (Brandfonbrener & Lederman, 2002; Chesky, Kondraske, Henoch, Hipple, & Rubin, 2002). In 2004, the Health Promotion in Schools of Music Conference (HPSM), in which ASTA partnered, gathered health professionals and music educators to a Tanglewood-style summit “designed to help music schools assist students in acquiring knowledge from qualified professionals regarding the prevention of performance injuries” (Chesky, 2004). HPSM has had widespread influence on music professional organizations, and eventually resulted in a new accreditation standard adopted by the National Association of Schools of Music (NASM) in 2011:

*It is the obligation of the institution that all students in music programs be fully apprised of health and safety issues, hazards, and procedures inherent in practice, performance, teaching and listening both in general and as applicable to their specific specializations. This includes but is not limited to information regarding hearing, vocal, and musculoskeletal health and injury prevention, and the use, proper handling, and operation of potentially dangerous materials, equipment, and technology. Music program policies, protocols, and operations must reflect attention to injury prevention and to the relationships among musicians’ health, the fitness and safety of equipment and technology, and the acoustic and other health-related conditions in practice, rehearsal, and performance facilities....* (NASM, 2012, p. 67)

How much do we really know about performance injuries and their prevention? Musicians, music educators, and movement and medical scientists have all investigated wellness from different perspectives with increasing frequency in the last quarter-century. In fact, the bibliography of resources housed on the Performing Arts Medicine website grew from one thousand in 1988 to 12,000 this past year (Performing Arts Medicine Association, n.d.). However, as I will discuss, there is still much to be learned, and in view of the NASM imperative, string researchers have a great opportunity to contribute to this body of knowledge.

Performing arts medicine for musicians is usually divided into four topic areas: musculoskeletal, psychological, vocal, and hearing health. I limited this article to an overview of research on musculoskeletal health, with an emphasis on string musicians. It is divided into four areas: epidemiology, referring to the “who, what, where, when” of injury; etiology, having to do with the “how” or the causes of injury; biomechanics, exploring the “why,” or underlying mechanisms of music-making and injury, and finally, prevention/intervention/pedagogical studies that address the question, “What can we do about it?” I explore the biomechanical and prevention categories in some detail, as they are the ones to
which string researchers may be able to contribute most because of their unique pedagogical perspective, as well as access to string playing populations. The NASM mandate encourages us to do so.

Musculoskeletal disorders are by far the most common of musicians’ complaints. According to the National Institute of Occupational Safety and Health, musculoskeletal disorder (MSD) is “an umbrella-type term that is designed to encompass all repetitive or cumulative problems, regardless of the occupational group involved, the mechanism of injury, or the precise clinical diagnosis” (Dawson, Charness, Goode, Lederman, & Newmark, 1998). For instrumental musicians these are known as playing-related musculoskeletal disorders (PRMD) (Zaza, 1998).

**Epidemiology**

Epidemiological research comprises descriptive studies that seek to answer such questions as who in a given population gets injured, how prevalent the injuries are, and the types of injuries that are experienced. The studies may be surveys, or a summary of cases seen in a medical clinic across time, called a case control series. Most of this research has been done by medical personnel.

A seminal study of 2,212 international orchestra and opera musicians (ICSOM) revealed that 84 percent of string players had at least one medical problem; 78 percent said that it was severe enough to affect their performance (Fishbein, Middlestadt, Ottati, Straus, & Ellis, 1988). Early studies of secondary students indicated a 33-50 percent prevalence of health problems (e.g. Fry, Ross, & Rutherford, 1988; Lockwood, 1988). Manchester (1988) reported the incidence of hand problems in college music performance students to be 8.5 per 100 students per year, and 9.6 for string players, over a study period of four years. Zaza (1998) reviewed several of these studies and found several methodological issues that might have inflated prevalence. In those that fit her criteria, excluding mild PRMD’s, prevalence decreased to 40 percent in adults and 17 percent in students. These figures are consistent with prevalence rates for other occupations in which repetitive motion is a factor (Zaza, 1998). More recently, however, Brandfonbrener (2009) found in a study of 330 college freshmen, that 86 percent of string players had a history of playing-related pain, though she did not have them rate severity of pain.

In string players, the most common PRMD’s involve muscle and tendon pain syndromes, which may be diagnosed as overuse, in which tissue is simply worked beyond its normal capacity; misuse; or other muscle or tendon disorders such as tendinitis (Dawson, et al., 1998). They may be mild or severe enough to

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3 Prevalence refers to the number of cases per 100 of a given population at a given point in time; incidence refers to the number of new cases per hundred of a given population over a given period of time. Both are usually expressed as percentages.
end a career. String players usually experience this pain in the upper extremities (including shoulder, hand, or elbow), the neck, or the back. Most studies indicate that upper string players are more likely to suffer than lower string players (Rardin, 2007). Less common are nerve entrapment syndromes, such as carpal tunnel syndrome, in which the median nerve is trapped at the wrist; cubital tunnel syndrome, in which the ulnar nerve is affected at the elbow, and thoracic outlet syndrome, where nerves are trapped in the neck and shoulder region. Focal dystonia, a sensorimotor disorder of the central nervous system that causes lack of control of fingers in string players, is relatively rare, with .5 to 2 percent of musicians thought to be affected (Dystonia Medical Research Foundation, 2012; Schuele & Lederman, 2004). However, it only occurs in one out of 3,400 in the general population (Schuele & Lederman, 2004).

Most epidemiological studies reveal that string players are injured more often than any instrument group except pianists. Students, professionals, and amateurs are all vulnerable and style does not seem to make a difference. Many studies indicate that women are more vulnerable than men (e.g., Fishbein, et al., 1988; Zaza & Farewell, 1997; Manchester, 1988; Shoup, 1995). Focal dystonia is the exception, usually occurring in mid-career professional men.

Etiology
Etiology deals with how string players become injured, or what are the risk factors. Those most cited in the literature are: overuse—from repetitive motion and force; misuse—or poor technique; deconditioning—or being out of shape; poor body alignment—posture; stress and fatigue; change of instrument or teacher; sudden increase in practice time; and hyperlaxity, commonly called “doublejointedness.” Seldom is just one factor involved (Brandfonbrener, 1998). Most of these are clinical case series findings, with the exception of a few studies on deconditioning.

Trunk endurance is widely accepted as a measure of conditioning; the higher the endurance score, the better in shape the person is. Kava, Larson, Stiller, & Maher (2010), studying the effects of exercise on music students, used a well-validated clinical measure (Ito, Shirado, Suzuki, Takahashi, Kaneda, & Strax, 1996) to test trunk flexor, extensor, and lateral endurance. The mean pre-test flexor and extensor scores of the 14 subjects were 44 percent and 47 percent lower, respectively, than those of comparable healthy subjects in another study who were more than twice as old (Ito, et al., 1996). A descriptive study of 33 incoming freshman music students (Palac, Grimshaw, Morin, Kava, Nestell, & Gates, 2009) yielded nearly identical scores to those of Kava, et al. on the three trunk endurance tests, indicating that they, too, were deconditioned.
Biomechanical Studies

Biomechanics is one branch of kinesiology; the study of human movement. Biomechanical research examines the neuromusculoskeletal mechanisms underlying music performance. It can reveal what is really going on when we play, as opposed to what we may perceive happening, and very often, the two are quite different. This can help determine why we get injured. In music, biomechanical research focuses on the kinematic and kinetic features of movement that produce sound. Kinematic features have to do with displacement in space, such as the path of a bow arm as it draws a straight bow, while kinetic features have to do with force or tension, such as the pressure of the fingers on the fingerboard.

There is a long and rich history of biomechanical study in both string and piano performance. The locus for sound production in both is largely external and visible, as opposed to that for winds or voice, where it is within the body. Musicians have initiated a rather large proportion of this research. In fact, Otto Ortman, a piano professor and director of the Peabody Conservatory, founded a biomechanics laboratory there in the early 20th Century (Harman, 1998). Some of the earliest research on string vibrato came from this lab (Cheslock, 1931). To date, the body of biomechanical research in string playing clusters around vibrato, bowing, and muscle tension in the upper extremities during performance, though there are other examples. For instance, Szende and Nemessuri (1971) studied not only the above but several other biological aspects of violin playing, such as the coordination of respiration and bowing. Bassist Kathleen Horvath (1994) studied the posture of 24 professional bassists using motion capture photography and two trained observers. She found that the posture of the bassists did not meet criteria developed from kinesiology research to adequately support their performance.

Studies of Bowing

Early studies of bowing involved the movement and graded force necessary to achieve a straight bow and good tone (e.g., Steinhausen, 1903; Trendelenburg, 1925). They were concerned with, for example, the classification of levers and fulcrum in the bow arm and hand. Their work relied on observation and analysis of the act of bowing in real time. In 1934, Hodgson placed a light on the bow hand of an expert performer and used time-lapsed photography to study bowing patterns, presaging the later use of motion capture videography. His results, which he called “cyclegraphs,” provided the first evidence of the curvilinear motions of the arm that result in a straight bow (Hodgson, 1958).

In the last 30 years, several investigators have used motion capture technology, in which performers are filmed from several angles to study aspects of bow motion. Violinist Peter Visentin, filming 11 professional violinists, found that motion at the shoulder and elbow joints was highly consistent across
subjects, while the fine motor motion of the wrist varied more widely (Shan & Visentin, 2003). Conversely, in another study on kinetic aspects of bowing, they found that right shoulder loads in eight professional violinists varied widely with the string played, while those at the elbow and wrist were more stable (Visentin & Shan, 2003). Helga Winold, a cellist herself, and her team found that high-level cellists use similar coordinated bow arm movement patterns in a constrained, well-delineated task, but that the patterns vary among cellists with musical intent, and within the same cellist with change of speed (Winold, Thelen, & Ulrich, 1994). These results led her to question the value of slow practice on passages that ultimately are played at faster tempos.

Vibrato Studies
Vibrato has been the subject many investigations employing visual or aural representations of the oscillations in pitch (e.g., Cheslock, 1931; Geringer & Allen, 2004; Geringer, Allen, & MacLeod, 2005, 2010; MacLeod, 2008), among other investigative techniques not discussed here. Many of the findings contradict traditional pedagogy, as demonstrated in a series of studies by Geringer, Allen, and MacLeod. When teaching does not align with physiological reality, students may be at risk for pain and tension. Geringer and Allen (2004) studied 40 university and high school violinists and cellists. They found that the vibrato rate was around 5.5 cycles per second for all performers, confirming most earlier research, but not tradition, which holds that lower strings vibrate more slowly. These student cellists vibrated at a similar rate as the violinists, and perhaps surprisingly, less widely in pitch (24 cents) than violinists (36 cents). They also found that the mean pitch was virtually the same for non-vibrated tones and vibrated tones, and that vibrated tones were more stable in pitch than non-vibrated. This suggests that the pedagogical intervention of practicing non-vibrated pitches to correct intonation may be an area where further study would be useful. Geringer, Allen and Macleod (2005) studied another sample of high school and university cellists and found that there was no consistency in the direction of the initial pitch change as vibrato was initiated. Excursion from pitch was equally above and below pitch center, confirming most previous research. This is contrary to many teachers’ insistence that vibrato is initiated with a downward motion from the pitch and oscillates back to the pitch. In my own teaching, I have observed that when students try to vibrate only from the pitch down, the motion can be tense and slow. MacLeod (2008) found that the width of vibrato in violin and viola students was larger in the upper than in lower register notes, though most teachers recommend that it be narrower when higher. Vibrato speed was faster, though not significantly, in higher registers as well, more consistent with pedagogical thinking. MacLeod also found a positive relationship between dynamic level and vibrato width: the louder the subjects played, the wider the vibrato. Violinists also vibrated more widely and faster than did violists.
The researchers also found that listeners’ perceived pitch of vibrated and non-vibrated tones was essentially the same (Geringer, MacLeod, & Allen, 2010). A more detailed summary of string vibrato research may be found in an earlier issue of the *String Research Journal* (Geringer, Allen, & MacLeod, 2010).

**Tension and Force**

Surface electromyography (EMG) is the primary instrument for measurement of muscular effort, or tension. A muscle at work, or in contraction, generates an electrical signal that detected by electrodes mounted on the skin surface over the muscle belly: The greater the tension, the stronger the signal. In some research, force generated at an interface (e.g., chin on the chinrest) is measured by force pads, plates, or pressure-sensitive tape.

An example of this type of research exists in a cluster of studies that examine the violin/chinrest/shoulder pad interface with the body. Levy and his team (1992) used surface EMG to measure tension in the shoulder muscles of 15 accomplished violinists with and without shoulder pads. They found that the use of the shoulder pad reduced tension significantly in two muscles: the trapezius, found in the upper back and the sternocleidomastoid, the large muscle in the front of the neck, while significantly increasing tension of the anterior deltoid, at the front of the upper arm. However, neck and shoulder dimensions were found to be significant predictors of tension. Their general conclusion was that, the greater the dimensions of the neck, the more the shoulder rest reduced tension. They recommended the use of shoulder pads to reduce the prevalence of musculoskeletal disorders in violinists (Levy, Lee, Brandfonbrener, Press, & Levy, 1992).

The effects of high, low, or no shoulder pads on both movement patterns (kinematics) using motion capture and tension as measured by surface EMG were studied recently (Rabufetti, Converti, Boccardi, & Ferrarin, 2007). Their only significant finding was that tension in the sternocleidomastoid muscle was inversely proportional to chinrest height. In terms of posture and movement, however, increasing shoulder pad height had a positive effect on reducing left shoulder rotation and elevation, as well as head rotation, but a negative affect on the rotation of the left forearm and the flexion of the shoulder. Many of these results are consistent with those of Levy, et al. (1992). In their conclusions, the researchers speculated whether changing chinrest heights, rather than shoulder pads, would produce more significant effects in posture and movement.

Okner, Kernozek, & Wade (1997) studied the effects of different chinrests, shoulder pads, and musical repertoire on pressure at the chinrest. They found that playing an excerpt from the Bruch Concerto produced significantly greater force and pressure values than did playing a Handel excerpt. The Wolf-Maestro™ chinrest, mounted partially over the tailpiece, produced significantly less pressure than did either the left-mounted Guarneri or the center-mounted
Johnson. Different shoulder pads did not generate clear differences. The authors concluded that repertoire must be taken into consideration when evaluating a chinrest/shoulder pad set-up, and cautioned that their results do not indicate what optimal pressure and force values at the chinrest should be. However, it is evident from this set of studies that there distinct advantages to using some combination of a chinrest and shoulder pad for several aspects of violin playing, especially for tension reduction in the neck and shoulder muscles.

According to Jim Kjelland’s comprehensive review (2000), EMG has also been used to examine muscle activity during certain techniques such as trills and vibrato and for diagnosis of performance injuries, comparison of methodologies for certain task accomplishments, and biofeedback training. This last use includes his own study, in which he determined that tone quality may be improved and muscle tension lessened through its use.

Some biomechanical studies have employed much simpler tools than EMG and motion capture technologies. For example, David Sogin and I (Palac & Sogin, 2005) used a simple nine-hole pegboard with violin students of different age and experience levels to demonstrate that violin training positively affects left-hand dexterity. Violinist and pedagogue Lynne Denig and luthier Gary Frisch, using chinrests of different heights, sizes, and shapes, and simple empirical observations, have developed best practice recommendations for chinrest fit with violinists and violists of different sizes and shapes (Frisch & Denig, 2008).

**Intervention and Prevention**

Considering the previous discussion it seems that most of string players’ PRMD’s could be prevented with some fairly simple alterations in pedagogy and practice. For example, if condition is a risk factor, then exercise should help. If a sudden increase in playing time increases the chance of injury, teachers could recommend a graduated schedule of return to practice after a break. Shoulder pads and variations in chinrest heights might prevent shoulder problems in violinists. However, to date, there is only a handful of studies on these issues, not nearly enough to establish efficacy of any particular protocol or strategy. String researchers are well-poised to add to the body of research on prevention and intervention, and to translate it to pedagogy.

What research there is does suggest that taking regular breaks and musically warming up reduces risk for either an initial or recurring PRMD (Zaza & Farewell, 1997). Exercise programs in core strength or endurance have been shown to be effective in reducing levels of perceived exertion in college music students (Ackermann, Adams, & Marshall, 2002; Kava, et al., 2010), as well as frequency of pain and pain intensity (Kava, et al., 2009). However, the number of subjects in each of these studies was small, and the intervention treatments less than a semester.
Though several colleges now offer some kind of coursework for musical health promotion (Health Promotion Courses, 2007; Spaulding, 1988), the long-term efficacy of prevention programs has not been fully explored. Studies of students report positive effects on psychological and physical health, as well as performance ability (Buchanan, 2010; Spahn, Hildebrandt, & Seidenglanz, 2001), or at least an increase in knowledge (Jansen, Dittrick, Narvaez, Boyette, & Staines, 2006). The duration of the interventions ranged from a few days (Jansen et al., 2006) to a semester (Buchanan, 2010) to a year (Spahn et al., 2001). The only longitudinal investigation (Zander, Voltmer, & Spahn, 2010) examined students’ physical and psychological health during the first two years of college music studies (N=247). Students in the intervention group (n=144) received two semesters of coursework on music health promotion during the first year, while those in the control group received none. Using standardized psychological and physical health questionnaires, the investigators ascertained that the students receiving coursework scored significantly better than the controls in psychological health scores both post-intervention and at the one-year follow up. They also demonstrated more health-seeking behavior. However, though physical health improved in both groups, there was no statistical difference between them attributable to the intervention. All music students pre-intervention had a higher number of psychological and physical issues than did medical students and those of other majors. The authors concluded that perhaps psychological issues respond more rapidly to intervention than do physical, and that physical health-promoting behaviors may take longer than psychological ones to take root in music students.

With the high rates of pain and injury among secondary and college music students (e.g., Lockwood, 1988; Brandfonbrener, 2009; Palac, et al., 2009, Zander, et al., 2010), it is apparent that prevention programs should begin early in their playing careers. For her dissertation, Rardin (2007), planned, implemented, and evaluated such a program with a group of students in a high school second orchestra (N=130, evenly split between control and intervention). Ten researcher-constructed multi-modality interventions delivered over a period of 10 weeks included education about injuries, and a carefully sequenced 10-15 minute warm-up with elements from Feldenkrais and Alexander body-awareness techniques, as well as physical therapy strength and stretching exercises. The outcome measure was a researcher-developed questionnaire concerning pain, tension, and discomfort, as well as attitudes about pain. The pain and tension scales were derived from those standardized by Goodman (Goodman & Staz, 1989). Pre- and post-intervention results for the experimental group indicated a significant decrease in pain frequency and severity scores. Those students were also significantly less likely to approve of playing with pain. There was, however, a small but significant increase in tension scores among them. Rardin speculated that post-intervention students may have been more aware of existing
tension due to their new-found awareness, rather than actually experiencing an increase in tension.

Cooper, Hamann, & Frost (2012) studied the effects of brief stretches developed by Winberg & Salus (1990) on the comfort levels of junior high and high school string players (N=100; 57 in the treatment group). The orchestra teacher conducted the exercises at 10-minute intervals during four rehearsals, and students filled out a researcher designed-questionnaire on discomfort before and after rehearsals. Participants in the control group experienced “normal” rehearsals. Mean discomfort scores dropped significantly from pre- to post-rehearsal in the treatment group, and rose significantly in the control group, indicating an immediate effect for a brief intervention. These studies, conducted by music educator researchers, serve as elegant models for the type of much-needed investigation that string researchers are capable of doing.

**Pedagogy**

Paul Rolland, with Richard Colwell, pioneered application of kinesiological research, including that of Steinhausen (1903) and Szende and Nemessuri (1971) to string pedagogy in the Illinois String Research Project. This resulted in the development of a new group string method, field-tested in several Illinois schools. *The Teaching in Action of String Playing* (2000), a film series and manual, document the project. Rolland incorporated techniques for appropriate body use in the method. Though a thorough description is beyond the scope of this discussion, an example is the teaching of weight transfer from foot-to-foot for balance, one of his primary principles. Rolland himself never published a method book with wide distribution. Nonetheless, his work has influenced most modern methods, and is still being analyzed and discussed in pedagogical forums today, even though it is over 40 years old.

The present generation of string teacher educators has received more training and exposure to procedures in research methodology compared to Rolland who had to rely on others to provide such information. String researchers today appear to be better equipped to follow Rolland’s example in applied pedagogical research.

**Summary and Conclusions**

The research above informs us that a great proportion of string players get hurt as a result of practicing their craft. It also suggests of number of things that teachers and players can do in order to reduce and prevent injury. In addition, this review reveals gaps in the study of musical wellness that string researchers can begin to address. For example, we have access to string students that enables us to do research such as the long-term efficacy of prevention programs.

Since even young string players are vulnerable to MSD’s, it is apparent that healthy practice should be initiated when students begin to study. Research
suggests that incorporating simple strategies, such as warming up and taking breaks, may go a long way in protecting string players from pain and injury. It is also apparent that teachers need to examine some long-held pedagogical notions about technique that are not compatible with biomechanical reality. The new NASM standard, as well as interest in our own profession, demonstrated by the increasing number of publications and conference sessions on this topic, signals that the time is ripe for more attention to these issues.

There is a lot of investigation yet to be done in string players’ health and wellness. String researchers have already provided valuable contributions in the areas of biomechanics, prevention, and pedagogy and are well qualified to add to this body of knowledge. Since there is currently a high degree of interest in musicians in the health sciences, particularly in occupational medicine and in the neurosciences, cross-disciplinary collaboration is a real possibility and is already occurring. It is time to expand our research, information, and publication paradigm to one that is inclusive of these areas, for our own benefit as well as for our students.

References


INFORMATION TO CONTRIBUTORS

Content
The editorial board of the String Research Journal (SRJ) welcomes research reports of a philosophical, historical, or scientific nature that enhance knowledge regarding the teaching and learning of string instruments and string music.

Style
Manuscripts should conform to the style recommended in the Publication Manual of the American Psychological Association (APA, 6th edition, 2009). For historical or philosophical papers, The Chicago Manual of Style (15th edition, 2003), or A Manual for Writers of Term Papers, Theses, and Dissertations (K. L. Turabian, 6th edition, 1996) are also acceptable. Styles must not be mixed. All manuscripts must be in English and must be double-spaced.

Submission Procedures
Manuscripts must be submitted electronically. Electronic submissions must be sent in Word.doc (or .docx) format, with the subject line: SRJ submission. Submissions must contain 2 attached files: one file consisting of the manuscript (12 point font, double-spaced), which should include an abstract (175 words or fewer); and a separate title page file containing the author’s contact information. Contact information should include author’s name, address, phone number, email address, and institutional affiliation. A statement affirming that the manuscript has not been published previously in part or in whole and that it is not under consideration by any other source should appear in the body of the e-mail. Manuscripts that are based on an author’s dissertation or thesis should be identified as such.

Please submit to:
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publication of the manuscript in SRJ without change or with minor changes, 2) suggest the author make suggested revisions and submit to SRJ again for further publication consideration, or 3) suggest that the manuscript not be considered further for publication in SRJ. The majority recommendation of the reviewers will normally determine whether a manuscript will be accepted for publication. The initial and each subsequent review will normally take approximately 2-3 months to complete, after which the author of the manuscript or the lead author of a multi-authored manuscript will be notified of the editorial decision.