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Editor's Preview

This issue contains articles that are conceptually very different from each other and from many of the articles that have appeared in past issues. This is a result of the continuing evolution of swimming research and of the journal. Consequently, the present articles have been categorized into Viewpoint articles which provides a forum for the exchange of research-based ideas concerning training, Original Investigations for articles describing the findings from an experimental approach to problems in swimming, and Clinical Studies that detail case studies or medical aspects of swimming. In future issues we hope to continue this type of variety and categorization although the opportunity to do so depends on the type of manuscripts submitted by authors and the quality or acceptability (as judged by the reviewers) of these manuscripts. Therefore, the categories that appear in this issue probably will not reappear in every issue of JSR but will be used when appropriate. By publishing in this format, the JSR can better serve the needs of the diverse swimming family that includes coaches, researchers, swimming medicine professionals, and many others.

Rick Sharp
The Residual Effects of Training

BRIAN E. COUNSELMAN
JAMES E. COUNSELMAN

Department of Intercollegiate Athletics
Indiana University
Bloomington, IN 47405

Beginning in 1980, the authors have been conducting formal and informal interviews with premier American swimmers—primarily sprinters. Some of them, after establishing world-class performances, have reported that, prior to major competition, they had radically altered their entire seasonal training plans, as compared to those they had followed in the past. This was especially true among swimmers who had extended their swimming careers far beyond their college days into their late twenties. Of similar interest are many Masters swimmers, who have reported reaching a high training status and actually approaching their age-group or collegiate performance without extensive training. This phenomenon is not limited to American swimmers, but has also been experienced on the international level. A number of Australian swimmers, who, after having ceased training and competing for several years, were able to attain excellent results following a moderate period of retraining. These sorts of reports, having been widely disseminated, have caused many athletes, especially the elite and mature performer, to question seriously much the training they have done in the past.

One of the problems in competitive swimming is the tendency to attribute success to immediate or short term factors. This is because as age-group swimmers begin their careers they often see continuous and dramatic improvements in performance with each successive meet they swim. They tend to believe that it is what they are doing for the moment that is making all the difference. At the most, they attribute success or failure on a season by season basis. But this is only partially true. They are bound to see substantial increases in performance early in their careers due simply to maturation and other age-dependent variables. Often oblivious to these factors, young swimmers are misled by reports of elite or mature athletes, who have radically altered their current seasonal training plans with drastic cutbacks in the total training load. Because these performers still achieve superior results, many believe that altering their training plans will also produce superior performance.

What has been forgotten, or is simply not realized, is that the future successes of mature or premier athletes is due, not only to what they are doing now, but also what they have done in the past. When one takes the time to examine the history of a premiere or mature athlete, one will typically see an extensive and continuous training background that can possibly span decades. The mature or elite performer usually does not alter his established training regimen because they believe this is beneficial; they reduce training because of increased social, familiar, and professional commitments. If, once this has been done, the elite or mature athlete continues to achieve or improve his success, the results are misinterpreted. Reduction of the training load, which is usually accomplished through the elimination of certain training means (i.e. over-distance, etcetera) is possible only because the elite or mature athlete is able to sustain certain physical qualities over extended periods of time without extensively training them in their current plans. This is because these qualities are retained as "training residuals", which are elicited by the "residual effect of training".

Long before the residual effect of training was conceptualized in the study of athletic performance, its existence was discovered in natural science. In studies described to the authors by the late, great exercise physiologist, W. W. Tuttle, the effects of inactivity were examined between groups of captured, migratory wild ducks and domesticated, sedentary ducks. Capillary density and mitochondrial mass of the muscle fibers from sacrificed animals showed that, even after extended periods of inactivity, the wild, migratory ducks still maintained a high level of these metabolic parameters over their domesticated counterparts. This, in part, gave rise to the concept that an extensive physical stimulus, like migratory flight, established the presence of physical
qualities that could be sustained for extended periods of time long after the physical stimulus had ceased.

The existence of long lasting training residuals is a phenomenon that is not recognized by many researchers. This is based on exercise physiology research that studied detraining, maintenance, and retraining. The extrapolation of this research, on the basis of which recommendations are made to sports training, is this: the cessation or reduction of training brings about profound losses of training benefits in relatively short time periods. It is also said that the magnitude, level of retention, and rate of gain or loss of these training benefits are not affected by the individual's previous training or sports background.

Although the residual effect of training is not generally recognized in exercise physiology, its existence is acknowledged in sports science. It is included in the category of "effects of training." This includes the immediate effects of training, the delayed effects of training, partial training effects, the accumulative effects of training, and the positive and negative effects of training. The last two are not considered so much direct training effects as they are transfers of training. Training effects, as a whole, are defined as changes that occur within the body as a result of training. Immediate training effects are those that occur as a result of a single training session. Accumulative training effects are the changes that occur as a result of a summation of many training sessions or even training seasons, etc. Partial training effects are those produced by a single training means (i.e. changes produced by strength loads, or endurance loads, or speed loads, etc.). There are several different types of delayed training effects, but the most familiar ones are those produced during compensatory adaptation. The residual effect of training is defined as the retention of physical changes following the cessation of training beyond time periods during which possible adaptation can take place.

These training effects can never be treated as operating independently of one another, and their interaction demonstrates the sheer complexity of athletic preparation. The residual effect of training is possibly the most complex training effect of all, because it is affected by all other training effects in various ways. The residual effect of training is also not limited to one physical system, since each system has its own rate of gain and loss.

The immediate effects of training are usually associated with a decrease in work capacity, or training fatigue. The nature of this decreased work capacity depends upon the overall demand of the particular training session, which in turn depends upon the content of specific work tasks and their dosage. Decreased work capacity should never be viewed as a gross effect, especially if the system of training used within the training scheme emphasizes the complex or integrated form of training session. In order to better understand the exact nature of the immediate effect of training, the partial effect of each training means must be understood. Partial training effects are changes produced by a particular training means, such as the execution of aerobic training loads, or anaerobic training loads, or maximal strength loads, etc. If there is a high mixture of training means within the training session, the overall demand has to be viewed as to how each training means within the session acts as a separate entity, eliciting its own particular stress upon the body before the total mixture of training is seen as a cumulative effect of the singular training session. With respect to endurance training, there are two basic categories of effects: response to the execution of aerobic training loads and response to the execution of anaerobic loads. Aerobic loads are considered of relatively low demand, which require high volume to elicit a significant enough training effect to induce training fatigue. Aerobic loads elicit adaptational effects which occur very slowly. But the number of biochemical pathways of the aerobics system are numerous, so the adaptations that occur from aerobic loads are also numerous, and these adaptations are lost very slowly once the training of aerobic endurance has ceased. Anaerobic training loads, when executed at sufficient dosage within a single training session, elicits profound stress and requires long recovery periods between their execution. Adaptation to anaerobic loads occurs very quickly, when compared to the rate of adaptation to aerobic loads, but there is a limited number of adaptations in the glycolytic machinery, and these adaptations are lost very quickly upon cessation of training anaerobic endurance. Thus, the training residuals developed from aerobic or anaerobic training vary greatly. The training residual developed from anaerobic loads is very small and is lost very quickly, so it cannot be seriously considered to be a long lasting training residual. This is why most training plans do not emphasize anaerobic loads early in the season. Aerobic loads required longer training plans, but develop greater, longer lasting training residuals.

It is the cumulative effect of training, more than anything else, that assures the development of training residuals. The cumulative effect of training is considered the primary factor for the future success of the sports master. The elite or mature athlete, who is typified by a highly stabilized physical condition, will be less inclined to increase performance results through recurrent super-adaptation and must rely on the phenomenon of delayed transformation. This term is another way of saying that improvement occurs as a result of cumulative training background. An ideal cumulative training background depends on continuity. This is everything from day-to-day training to season and multi-year training. When a suitable long-term background is developed, the magnitude of the training residual will be very high,
relative to the athlete's predisposition for retention. In detrainment, those individuals with greater training residuals have slower rates of loss of physical capacity, compared with those with smaller residuals. In retraining, athletes with longer training histories and higher training residuals regain physical abilities much more quickly.

There are three different types of delayed training effects. The best known and desirable of these are the physical changes that constitute super-adaptation—sometimes termed "over-compensation" or "exaltation"—at the end of a training cycle. Adaptation occurs during unloading (reduced work) or restoration, thus being referred to as "compensatory" adaptation. The most commonly known delayed training effect of this type is the adaptation that occurs, following an aggregation of training sessions that constitutes the weekly micro-cycle. Sports scientists are beginning to discover that there are much longer or extended delayed training effects that require months before super-adaptation is realized. Sometimes delayed training effects are confused with effects of training residuals. As an example, some athletes, who train chronically with little rest or chance for adaptation, will realize dramatic improvement in performance years after they discontinue chronic training and/or the content of training is changed. It is in these cases that the change in the training load is not augmented by a training residual only, but by an extended delayed training effect that has resulted in a dramatically belated period of over-compensation.

Although the existence of training residuals depends primarily upon the cumulative effect of training, how well training residuals are developed or stabilized can be further compounded by the positive and negative transfer of training effects. Sports training means and methods must never be viewed as always having a gross beneficial effect on all the physical systems. Training means have very specialized effects, which can affect each system in different ways. That is because each system has its own specialized mechanism of adaptation. While one training method might produce beneficial adaptations in one system or ability, it can have a negative or counterproductive effect on another system of physical ability. Though sports science has formulated fairly simple and direct lines of transfer of training, being able to delineate direct transfer of training and to predict its effect on performance is not easy. It depends upon the needs of the sport and, more importantly, upon the needs of the athlete. Although it is acknowledged that high strength loads can have a negative effect on endurance, a swimmer can improve endurance results by making strength gains that will allow him to alternate the activation of motor units, increasing energy efficiency as well as improving total propulsive output with each stroke. On the other hand, excessive strength gains can result in muscle hypertrophy, which can increase resistance in the water and reduce capillary density in the working muscle.

Another consideration with training transfers which increases the complexity of understanding training effects is that training transfer, either negative or positive, doesn't always act both ways. While strength work can negatively affect endurance, endurance work does not necessarily have negative effects on strength. It is a matter of how much volume of each training means is executed, when the development of one training ability takes precedence over another. Indeed, priorities must be established, if the desired training residuals are to be developed. Working on either developing just endurance, or just developing strength, will suffer at the expense of another. But this is considered by many sports theorists to be more advantageous than attempting to execute a combined program that executes a "balanced" distribution of both strength work and endurance work. This is because it is in this type of program that non-significant gains in both strength or endurance are achieved, when compared to the former programs that emphasized singular development of either endurance or strength.

Thus, transfers of training can be a subtle complexity of tradeoffs. There is great controversy and disagreement as to exactly how tradeoffs in training actually work. But what is universally agreed upon is this: an athlete cannot instill maximum endurance, strength, and speed qualities in the muscle all at the same time. This concept forms one of the factors for the pursuit of periodization in training. Although some training systems are based on the theory of multi-lateral development, which works on the concept that endurance, strength, and speed can be developed in a parallel manner, most multi-lateral training systems change the volume or dosage of each training means to conform to the principle of the development of the leading functions. This development is dictated by the heterochrony of training adaptation of each physical quality.

On the basis of this sports theory, the reliance on training residuals takes on greater meaning in its relation to transfers of training. When peaking for major competition, there are performance demands that actually call for the diminishment of some physical qualities. This prevents counter-productive effects on the athlete's holistic competitive state. For instance, maximal strength loads are often executed in the first month of the training plan with the emphasis of achieving optimal strength levels early in the season. As the season progresses, maximal, strength loads are diminished, not increased. This is because the continued execution of high strength loads can interfere with the more current development of speed and specialized endurance qualities. During the pre-competitive phase, it is actually hoped that the peak level of maximal strength will
diminish. Its rate of loss must not be high, relying on the training residual—or delayed training effect, depending on how the strength load was organized—to sustain a level of strength that works with, and not against, all other physical abilities. Training residuals do not themselves increase performance by working at peak capacity during the major competitive period. This is because the time period for possible adaptation has lapsed, but training residuals can be sustained over long time periods without significant loss and, more importantly, do not have negative effects on other physical abilities under current training.

The desired process of “interference” caused by transfers of training have been brought to the fore in the implementation of long-term training plans for Olympic hopefuls. The Olympic cycle, sometimes known as the quadrennial plan, is a four year training cycle that emphasizes the development of the highest possible level of endurance abilities in the first year of training. The level of endurance developed, it is hoped, exceeds the endurance demands of the athlete’s specialized events and does so at the cost of diminished emphasis on strength and speed abilities. In the later years, or phases, of the plan, the content of the training is changed. Endurance work is diminished to maintenance levels and greater emphasis is placed on the development of strength and speed abilities. The last year of the Olympic cycle emphasizes the unity of abilities in developing competitive-specific qualities. It is anticipated that peak endurance qualities will gradually diminish. The long-lasting training residuals of endurance training will be retained to the point to where the appropriate level of endurance is achieved during Olympic competition. This process prevents the interference of transfers of training in the training plan where they are not needed. In training Mark Spitz, prior to the 1972 Munich Olympics, for the first two years greater emphasis was placed on training him for the 550 yard freestyle. It was anticipated at this time, however, that his greatest success would be achieved in the 100 and 200 events. As he approached Olympic competition, more emphasis was placed on training for shorter events. This approach guaranteed the proper development of the leading functions with the appropriate types of training residuals.

As mentioned before, when a physical system or ability exists as a training residual, it will not act as a negative transfer of training because its development has ceased. The purpose of training in the later phases of the training plan is not only to stress the peak development of physical abilities having smaller training residuals, but is also to gauge and control the realization of delayed training effects, as well as to control the rate of retention or loss of training residuals. The stabilization of training residuals must never be disrupted by inappropriate work, and the rate of loss must never be over-accelerated by inordinate devotion to training means that have strong negative effects. For instance, the rate of loss for the training residual of endurance can be accelerated by the excessive and prolonged use of maximal strength training loads. This is especially true if the maximal strength loads constitutes the sole or primary training stimulus under current use. Even a long-term, multi-year accumulative training residual can be wiped out in a relatively short time period in this manner. In such a case, even sporadic endurance maintenance work will slow this rate of loss. This particular example has been used because the authors have encountered instances of elite swimmers, mostly sprinters, who have completely abandoned any endurance training means and have resorted to the exclusive use of strength training as a possible means of sustaining or even improving speed qualities along with sporadic sprint work. Not only did most of these athletes lose all their endurance ability, they often have lost much of their speed potential as well. Though strength qualities are needed to enhance speed abilities, strength training has been shown to have an eventual negative training effect on speed.

Achieving training residuals depends on yet another factor: the athlete’s initial and relative predisposition to acquire and maintain them. By “initial” is meant a point at which record-keeping for an athlete begins, while by “relative” is meant possible changes not entirely due to training, but also to changes in physical and mental hygiene, etc. The term “predisposition” indicates some innate, usually genetic potential, that causes changes that may, but more likely will not, be affected by training. Factors like height, physical build, muscle fiber type distribution, visual acuity, etc. are usual results of innate disposition. In the study of elite athletes, there is some current thinking that there is a predisposition to elite performance itself. Such terms as “raw talent” of the “right stuff” come to mind. Although many researchers claim that the rate of achieving or losing physical qualities have nothing to do with an athlete’s background, which includes performance accomplishments, it is these same exercise researchers who have conducted longitudinal and cross-sectional studies, which determined that the achievement of superior physical qualities is directly related to both an athlete’s extent of training and level of athletic accomplishment. This information forms the basis for the following sports theory: elite performers possess qualities that allow them to achieve training residuals, which can be maintained longer, lost more slowly, and regained more quickly, than in athletes who have less training background and less predisposition for elite performance.

Being predisposed towards a course of development can explain why some athletes make relatively high gains in physical abilities without training for them. This is
possible even in the mature athlete. In the past, the common belief had it that, past a certain age, most physical abilities either stabilize or diminish. Many mature athletes are now reporting gains in physical abilities without even training them, as in the case of some Master swimmers who have been able to surpass earlier performances from their supposed "peak" years. As an example, many Master swimmers experience increased performance results due to strength gains, although they have undergone no strength training. This could be due to having had natural strength gains inhibited by a transfer of training like chronic endurance loads, but it could also be due to being predisposed to making strength gains at a later age. Whatever the case, it should not be assumed that strength gains are the singular cause of performance improvement. Without training residuals of other physical abilities, the mature athlete could expect to continue to make performance gains only by returning to the use of even greater training workloads than he had executed in earlier years. This is based on the assumption that performance increases are only possible through equivalent increases in "peak" trainedness.

The "gross" or "total" residual effect of training must be differentiated into a number of biological or physical systems. These systems have different and varying effects on total athletic performance. As stated in the concept of heterochronality of training, there are different rates of adaptation of the various systems. The system also vary in the retention and rate of loss or gain of trainedness, their cumulative effect defining the total or gross training residual. Some training residuals are lost within days, while others are retained almost indefinitely. To illustrate this point, a model has been devised, which illustrates the magnitude and rate of retention and loss of each physical system. (Figure 1) The authors are not proposing that this model works the same in all athletes; the degree or rate of loss of trainedness in any of these systems is always individual. But there are some systems that usually display consistency in being able to be retained longer than others.

The first system in this model is what can be referred to as "peak metabolic productivity". It is subdivided into two different sub-systems: anaerobic and aerobic. Peak anaerobic metabolic productivity, which is reflected in the increase or decrease of glycolytic enzymes, has the smallest training residual of all the systems. Its retention or rate of loss can be measured within days for some processes, while others are lost within a few weeks. Peak aerobic metabolic productivity, which is reflected in changes in the amount of aerobic enzymes, respiratory parameters, etc., has a longer training residual, which can be retained for months. Although it can be argued that this is not a substantial training residual, peak aerobic metabolic productivity does not reflect all the qualities of endurance retained in different systems.

The next system that possesses a significantly higher training residual than peak metabolic productivity is the cardiovascular-respiratory system, which may also be termed the circulatory system, includes everything from capillary density in muscle tissue to cardiac parameters such as heart size and stroke volume. The respiratory system also possesses an equivalent and related training residual to that of the cardiovascular system. The physical changes in the respiratory system associated with training is an increase in lung mass, and, thereby, an increase in the respiratory area of the lungs (the alveoli).

The study of capillary density in muscle tissue is one area of research that is beginning to show clear proof of the existence of training residuals. It has been shown in the study of muscle blood flow that post-exercise hyperemia (blood build-up) is less evident in trained as opposed to untrained individuals. Thus it appears that training can increase effective muscle blood flow by either increasing capillary numbers or by increased dilatation of existing capillaries. Carrow, et al (2) was the first to suggest that increased blood flow was due to an increase in the number of capillaries. Some studies using biopsy samples failed to show increased capillary number, but most of these used relatively brief training periods during the research. This indicated to some researchers that increased capillarization could occur due to chronic training over much longer time periods—the all-important consideration when developing training residuals. If there are indeed no new capillaries developed, then it is certain that increased muscle blood
flow is due to increased dilatation of existing capillaries. This could also include the opening of previously unused, vestigial capillaries, which would have remained closed if not for chronic training effects. Whether increased capillary density is due to the formation of new capillaries or the opening of existing vessels is entirely theoretical, one theory suggesting that probably both occur. How this relates to the residual effect of training is as follows: chronic and extensive physical training results in increased capillarization of muscle either by the formation of new capillaries or the opening of existing capillaries. Detraining will ultimately result in at least the closing of some existing capillaries, but the rate of closure is affected by the magnitude of the training residual. The retention of higher levels of capillary density in the muscle of extensively trained runners, as opposed to briefly trained subjects, during enforced and prolonged periods of inactivity (3), demonstrates that capillary density is affected by an individual’s training background, thus revealing a residual effect. In addition to capillary density, heart parameters, such as heart size and stroke volume are studied in cross-sectional research (4, 5, 7). These parameters display the greatest magnitude of difference, when compared to athletes with smaller training backgrounds. This supports a residual training theory to the effect that the greater the magnitude of a given physical parameter, the greater its training residual.

The importance of the longer lasting training residual on endurance performance results, when compared to cellular metabolic productivity, has been cited in sports theory publications. Barnard and Peter (1) were the first to discover there was a poor correlation between endurance results and the presence of metabolic components (cytochrome concentration). This and other studies have shown that the capacity for energy production (oxidative phosphorylation) did not correlate with improved endurance performance. Although maximal oxygen consumption is related to performance results, maximum oxygen consumption is not limited by the metabolic apparatus at the cellular level. This would indicate that the cardiovascular system is the limiting factor. The study conducted by Saltin (7) indicates that stroke volume is the physical parameter that contributes the most to maximal oxygen consumption with prolonged training. Thus, it is entirely possible that the gross training residual for endurance qualities can be sustained for optimal performance levels by longer lasting training residuals of other systems than that of the metabolic energy mechanism.

The next physical system to be discussed reveals a higher training residual than the cardiovascular/respiratory system. It is the musculoskeletal system, and it includes modifications of the muscle at the cellular level not directly related to energy acquisition, such as muscle hypertrophy and muscle hyperplasia. Also included is modification of fiber types. The two previously mentioned types of modification determine the acquisition of strength abilities, such as maximal strength or strength endurance. Also included is the training of the reactive and elastic properties of the muscle to facilitate the speed strength qualities of the muscle. The training residuals of the musculoskeletal system can be retained for years, even when accounting for further improvements, which can occur as a result of continued maturation, or losses due to atrophy caused by illness or injury.

The last physical system in the model has the longest lasting training residual. It is the neuromuscular system and includes the acquisition of coordination, movement skill, and technical preparation. Also included are such factors as kinesthetic awareness and proprioceptive sensitivity. It is the opinion of many sports scientists that the achievement of sports mastery is reflected most in the achievement of movement skill. Once achieved and reinforced through the proper regulation of training tasks, the retention of neuromuscular capability can be retained almost indefinitely. It is also noted by sports scientists that movement skill or efficiency has definite positive effects on the athlete’s acquisition of physical trainedness. Greater levels of muscular energy efficiency are considered the leading factor to achieving the desired content of training aimed at superior physiological preparation (6). Can the magnitude of the neuromuscular training residual be affected by the level of movement skill achieved, and can this particular training residual have a direct effect on physiological training residuals? This is entirely possible.

As stated before, there is no simple manner or direction by which the retention or rate of gain of each system can occur beyond another. This is because most of these systems are controlled by complex hormonal and neurogenic factors, as well as the tendency for each to affect one another. Although the effects of training are measured by changes in the physical systems, it is in the nervous system where the greatest effects of training stimulus are seen. It is also in the nervous system where the greatest potential for training residuals are likely to exist. The nervous system can store and recall vital information, created by prolonged training influences. This, in turn, can create a cascade of complex neurogenic and hormonal factors, which can affect the retention of physical parameters. This aspect of training is not regularly studied by exercise physiologists. One of the concepts that has been formulated concerning neurally-induced training residuals, is that of “physiological recall”. This concept states that, if the athlete’s background is extensive enough, the athlete may be able to recall and regain states of trainedness at a much higher rate as compared with subjects with smaller training backgrounds. The rate of physiological recall
is directly affected by the magnitude of the training residual. It is entirely possible that physiological recall need not be neurally induced, especially at the microvascular level. Once vestigial capillaries have been opened by chronic training effects, it will only require local physiological changes to reopen them without neural stimulation.

In order to achieve the desired long-lasting training residuals, it is recommended to do the following:

(1) Begin training at an early age so that suitable training residuals may be available during the athlete’s peak, competitive career phase. Training should have a high degree of continuity and should be more or less year-round, with day-to-day, month-to-month consistency. Training should never be erratic with prolonged periods of inactivity. Breaks between seasons should be of a transitional nature, with reduced workloads, but never complete cessation of training.

(2) Throughout the athlete’s competitive career, but especially in the early years of training, the total workload of each training season should conform to the recommended yearly, maximal training loads. Training below this yearly, maximal training load will result in an insufficient cumulative training effect, while exceeding it can result in over-training. The usual maximal training loads are age-dependent and are increased with each successive year. The yearly maximal training loads also differ in their distribution and periodization, which, in turn, is dependent on the ability level of the athlete, which is also dependent on the age of the athlete. This ensures a gradual, progressive increase with each successive year of training until an age or ability level is reached at which the workloads can become relatively stable.

(3) The content of endurance training should be primarily of an aerobic nature, especially in the early years of age-group competition. With each successive year the content of the yearly, maximal training load will also change, shifting towards more work done in the mixed/anaerobic zones. Anaerobic lactate (speed endurance) or anaerobic alactate work (maximal speed or sprint) should never dominate as the main component of training. This latter can only be done if the total training load is drastically decreased and should not be attempted by the beginning or intermediate-level athlete. It is not considered to be sound practice for any athlete, with the possible exception of the elite or mature sprinters.

(4) Strength training should begin at an age at which the individual’s functional strength level is sufficiently high, due to maturation. In the early years of strength training, strength work should be viewed as a supplemental means of enhancing maturational strength gains. Strength loads, like endurance loads, should be progressively increased each year, but the magnitude of increase should coincide with changes in the rates of potential strength gains due to maturation. Usually, a point is reached at which the rate of strength gains levels off. More time should be spent on developing specialized and competitive-specific qualities, so the time spent on maximal strength training should actually diminish. Continuing to increase maximal strength work past a certain level of sports mastery can have eventual counterproductive effects.

(5) The development of speed abilities is tied in with the development of the neuromuscular system and the contractile properties of the muscle. In the long term training of speed abilities, the desired goal is not so much the development of a speed residual, as it is the prevention of a speed barrier. In the early years of training, the prevention of a speed barrier is done by insuring that the athlete’s technical preparation allows him to make gains in movement skill commensurate with gains in endurance and strength. As the athlete matures, the avoidance of the speed barrier will become less a factor due to technical limitations, and more a factor of how well the reactive and elastic contractile capabilities of the muscle are trained. This is done through more specialized strength training, which emphasizes the development of the athlete’s speed-strength and movement-speed qualities.

Summary

The acquisition of training residuals, or the residual effect of training, is the least understood aspect of athletic preparation. How training residuals are achieved depends largely on a cumulative effect, which is reflected in the total volume of the training load, as well as the content of the training load. The total training load has certain quantitative objectives that must be attained. As for the content of training, it must change to suit the complexity of developing different abilities. In the early years or phases of training, emphasis should be placed on developing physical abilities or systems that require longer development, but also sustain their effects longer. This will ensure the development of physical qualities that will allow the athlete to pursue changes in training later in his career. The recent advocacy and implementation of training theory that stresses the singular use of high intensity-low volume training throughout an athlete’s career will establish a new pattern of training: a reduction in the total training load, frequency of training, and elimination of certain training methods. This will reduce the cumulative effect of training, thus reducing the magnitude of needed training residuals. Without the desired training residuals, it will be difficult to develop all the desired qualities, especially those which allow the content of training to be changed without loss of trainedness.

Another important factor in considering how train-
ing residuals contribute to sustaining optimal performance is the demands of the competitive events. In the shorter duration events like the 50 and 100, which make greater demands on strength and speed abilities, it is possible for the sprinter to depend on a lower endurance training residual for a relatively long period of time. In the middle distance and long distance events, which make greater demands on high endurance capability, the athlete must depend on both a higher magnitude endurance training residual and current peak endurance trainedness. The longer distance swimmer cannot rely on his training residual alone to sustain desirable performance levels, if the swimmer considers possible long term cutbacks in training.

References


Physiologic and Physical Correlates of Swimming Performance

Panagiotis P. Klenrou, M.Sc.
Richard R. Montpetit, Ph.D.

Département d’Éducation Physique, Université de Montréal
C.P. 6128, succursale A, Montréal, Québec, H3C 3J7, Canada.

Abstract

The contribution of physical characteristics, stroke rate, maximal aerobic power, swimming economy and swimming power to sprint and middle-distance swimming performance have been analysed in twelve of 100 m and thirteen of 400 m freestyle swimmers. The 20 seconds post exercise $\dot{V}_O_2$ technique was used to estimate steady state $\dot{V}_O_2$ and then to calculate the energy cost at submaximal velocities adjusted for body mass. Swimming power was measured during partially tethered swimming by employing an accommodating-resistance device. As expected, the factors which determined the performance level in the two crawl events are different. Sprints have been found to possess a significantly greater swimming power than the 400 m swimmers. According to the partial correlation results, height, armspan and power were well correlated with performance in 100 m and the combination of height, armspan, maximal stroke rate ($\dot{S}_{max}$) and power could predict the performance with an accuracy of $\pm 1.8\%\ (r=0.84,\ SEE=1.03)$. For the 400 m crawl, maximal velocity ($v_{max}$) and $\dot{S}_{max}$ were significantly correlated with performance. Further, the best predictors of the 400 m performance were height, $\dot{S}_{max}$ and submaximal $O_2$ uptake at $1.3\ m\ s^{-1}$ adjusted for body mass ($WA - \dot{V}_O_2$). These variables may explain together up to $68\%$ of the variance in the performance with an overall accuracy of $\pm 1.3\%$.

Introduction

Previous investigations have attempted to identify the physiological attributes associated with swimming success. Identification of these attributes would facilitate development of appropriate training regimens. Although many attributes and limitations of swimming have been suggested, controversy still exists as to their actual role in determining swimming performance. As it is generally accepted, specific particular physiologic attributes constitute important prerequisites for successful participation in all the swimming events. Khosla (14) indicated that increased height in some events were related to better performance. It is also agreed that short-distance freestyle and backstroke swimmers are the tallest among swimmers (15). Thus a bias in favour of the taller swimmers is apparent which may be derived from the greater distance covered by their limbs during a stroke or the “froude effect”. Stroke rate and stroke length may also be important factors in swimming performance by affecting swimming economy (3, 26).

A high maximal oxygen uptake ($\dot{V}_O_{2,\max}$) as well as good swimming economy have also been associated with successful swimming performance especially in middle distance swimming (1,2,7,17,23,26). In addition, recent studies have demonstrated a close relationship between power measured with the biokinetic swim bench and sprint swimming performance (5,16,13,22).

The purpose of this study was to examine which of the above physical, functional and metabolic characteristics may be the most important factors contributing to the variability of results in competitive freestyle swimming performance. Two different crawl events were examined, a short distance (100 m) and a middle distance more aerobic event, the 400 m.

Methods

Subjects

Twenty five male Canadian age-group swimmers were recruited as subjects for this study. Twelve of them trained and competed regularly in 100 m crawl, while thirteen trained and competed in 400 m crawl. According to the Canadian rating table (1000 representing the right best scores in the event), the 100 m swimmers rated 964 and the 400 m swimmers 957. The subject’s mean (± SD) age was 16.8 ± 2.2 years.

Testing procedures

Subjects reported their best recent performance (±
swimming economy over a wide range of velocities is clearly affected by the individual's total body mass, oxygen consumption at a given submaximal velocity in this study was adjusted for body mass. This adjustment was made by the method of Henry (12):

$$WA_\text{-O}_2 = \text{mean} V_\text{o}_2 + (V_\text{o}_2, \text{indiv.} - V_\text{o}_2, \text{pred.})$$

Where $WA_\text{-O}_2$ represents the $V_\text{o}_2$ at 1.3 m s$^{-1}$ adjusted for body mass. $WA_\text{-O}_2$ is thus an expression of the swimming economy.

**Power measurement**

In an effort to employ a test for swimming-specific power, the CYBEX system was adapted for use during partially tethered swimming (Figure 1). This approach to measure force and power allows the swimmer to swim away from the apparatus, at a previously determined speed, while the excess force exerted against the water is recorded by a transducer within the CYBEX apparatus.

After attaching a leather harness belt around his waist and shoulder, each swimmer took one or two practice swims to become familiar with the apparatus and the sensation of swimming against a resistance. In each trial the subjects swam against the external force (provided by the CYBEX) for a distance of 15 m.

All swimmers were tested with a number of speed settings on the CYBEX and the best results were observed at a speed of 1.1 m s$^{-1}$. This means that when the swimmers attempted to swim away from the apparatus at speeds equal or greater than 1.1 m s$^{-1}$, tension was developed along the cable to the force transducer within the CYBEX. This tension was proportional to the force of swimming. Since both the force (Newton) and the speed (m s$^{-1}$) were recorded, power in Watts was obtained by the product of force x speed.

**Results**

The 100 m and 400 m swimmers presented similar
PHYSIOLOGICAL AND PHYSICAL CORRELATES
OF SWIMMING PERFORMANCE

Table 1.
Physical characteristics of subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>x ± SD</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>65.8 ± 3.4</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.0 ± 7.5</td>
<td></td>
</tr>
<tr>
<td>Armspan (cm)</td>
<td>182.2 ± 7.7</td>
<td></td>
</tr>
<tr>
<td>Chest circ. (cm)</td>
<td>90.7 ± 3.6</td>
<td></td>
</tr>
</tbody>
</table>

Physical characteristics (Table 1). Mean \( \dot{V}_{O2\text{max}} \), \( WA - \dot{V}_{O2\text{r}} \) @ 1.3 m s\(^{-1}\), maximal velocity (\( v_{\text{max}} \)) and maximal stroke rate (\( \dot{S}_{\text{max}} \)) were also similar but the mean power was significantly higher in the sprinters (Table 2).

Correlations between the physical, functional and metabolic data and the performance for 100 m crawl swimmers are presented in Table 3 and those for the 400 m crawl swimmers are presented in Table 4. Height was well correlated (\( r = 0.60 \)) with performance in 100 m but not with performance in 400 m (\( r = 0.18 \)). However, maximal velocity measured during the test and maximal stroke rate were significantly correlated with performance in 400 m (\( r = 0.58 \) and 0.70 respectively) but not with performance in 100 m (\( r = 0.19 \) and 0.09 respectively). Armspan and power were not generally correlated with performance in both groups but they were included in the final model chosen by the forward regression analysis for predicting performance in 100 m freestyle swimming (Table 5).

Height was the first variable entered in this equation which with the other three variables explain 71% of the total variation observed in performance. In addition, a partial correlation analysis was executed between performance, height, armspan, \( v_{\text{max}} \), \( \dot{S}_{\text{max}} \) and swimming power. In this case where the other selected variables remained constant, the relationship between 100 m

Table 2.
Functional and metabolic characteristics of subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>x ± SD</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \dot{V}_{O2\text{max}} ) (1 min(^{-1}))</td>
<td>4.76 ± 0.6</td>
<td>4.68 ± 0.6</td>
</tr>
<tr>
<td>( v_{\text{max}} ) (m s(^{-1}))</td>
<td>1.44 ± 0.06</td>
<td>1.45 ± 0.04</td>
</tr>
<tr>
<td>( \dot{S}_{\text{max}} ) (str min(^{-1}))</td>
<td>41.6 ± 3.5</td>
<td>42.7 ± 3.6</td>
</tr>
<tr>
<td>( WA - \dot{V}_{O2\text{r}} ) @1.3 (1 min(^{-1}))</td>
<td>3.26 ± 0.5</td>
<td>3.38 ± 0.05</td>
</tr>
<tr>
<td>( S ) @1.3 (str min(^{-1}))</td>
<td>35.5 ± 2.3</td>
<td>35.4 ± 2.6</td>
</tr>
<tr>
<td>Power (Watts)</td>
<td>76.9 ± 11.3</td>
<td>67.1 ± 12.8</td>
</tr>
</tbody>
</table>

respectively. Armspan and power were not generally correlated with performance in both groups but they were included in the final model chosen by the forward regression analysis for predicting performance in 100 m freestyle swimming (Table 5).

Height was the first variable entered in this equation which with the other three variables explain 71% of the total variation observed in performance. In addition, a partial correlation analysis was executed between performance, height, armspan, \( v_{\text{max}} \), \( \dot{S}_{\text{max}} \) and swimming power. In this case where the other selected variables remained constant, the relationship between 100 m

Table 3.
Correlations between the physical, functional and metabolic variables and the 100 m crawl performing time in seconds (\( T_{100} \)).

<table>
<thead>
<tr>
<th>Variable</th>
<th>( T_{100} )</th>
<th>Weight</th>
<th>Height</th>
<th>Armspan</th>
<th>Chest circ.</th>
<th>( \dot{V}_{O2\text{max}} )</th>
<th>( v_{\text{max}} )</th>
<th>( \dot{S}_{\text{max}} )</th>
<th>( WA - \dot{V}_{O2\text{r}} )</th>
<th>( S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>-0.60*</td>
<td>0.75**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armspan</td>
<td>NS</td>
<td>0.76**</td>
<td>0.86**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest circ.</td>
<td>NS</td>
<td>0.69**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \dot{V}_{O2\text{max}} )</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( v_{\text{max}} )</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>( \dot{S}_{\text{max}} )</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( WA - \dot{V}_{O2\text{r}} )</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
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<tr>
<td>( S )</td>
<td>NS</td>
<td>0.72**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**\( p ≤ 0.01; * p ≤ 0.05 \)

Table 4.
Correlations between the physical, functional and metabolic variables and the 400 m crawl performing time in seconds (\( T_{400} \)).

<table>
<thead>
<tr>
<th>Variable</th>
<th>( T_{400} )</th>
<th>Weight</th>
<th>Height</th>
<th>Armspan</th>
<th>Chest circ.</th>
<th>( \dot{V}_{O2\text{max}} )</th>
<th>( v_{\text{max}} )</th>
<th>( \dot{S}_{\text{max}} )</th>
<th>( WA - \dot{V}_{O2\text{r}} )</th>
<th>( S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>NS</td>
<td>0.88**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armspan</td>
<td>NS</td>
<td>0.84**</td>
<td>0.90**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest circ.</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \dot{V}_{O2\text{max}} )</td>
<td>0.58*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( v_{\text{max}} )</td>
<td>-0.70**</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \dot{S}_{\text{max}} )</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( WA - \dot{V}_{O2\text{r}} )</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S )</td>
<td>NS</td>
<td>0.86**</td>
<td>0.75**</td>
<td>0.73**</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**\( p ≤ 0.01; * p ≤ 0.05 \)
Table 5.
Regression analysis for predicting performance in 100 m and 400 m freestyle swimming.

<table>
<thead>
<tr>
<th>Variables</th>
<th>R</th>
<th>R²</th>
<th>SEE</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100 m</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (Ht)</td>
<td>0.60</td>
<td>0.36</td>
<td>1.31</td>
<td>( Y = 82.7 - 0.153(Ht) )</td>
</tr>
<tr>
<td>Armspan (As), Ht</td>
<td>0.75</td>
<td>0.56</td>
<td>1.14</td>
<td>( Y = 78.2 + 0.21(As) - 0.35 ) (Ht)</td>
</tr>
<tr>
<td>Power (P), As, Ht</td>
<td>0.81</td>
<td>0.66</td>
<td>1.06</td>
<td>( Y = 77.1 + 0.05(P) + 0.03(As) - 0.34(Ht) )</td>
</tr>
<tr>
<td><strong>( S_{\text{max}} )</strong></td>
<td>0.84</td>
<td>0.71</td>
<td>1.03</td>
<td>( Y = 69.9 + 0.18(S_{\text{max}}) - 0.07(P) + 0.36(As) - 0.4(Ht) )</td>
</tr>
<tr>
<td><strong>400 m</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( S_{\text{max}} )</td>
<td>0.69</td>
<td>0.48</td>
<td>3.9</td>
<td>( Y = 297.3 - 1.01(S_{\text{max}}) )</td>
</tr>
<tr>
<td>Height (Ht), ( S_{\text{max}} )</td>
<td>0.76</td>
<td>0.57</td>
<td>3.4</td>
<td>( Y = 356.1 - 0.29(Ht) - 1.19(S_{\text{max}}) )</td>
</tr>
<tr>
<td>( W \alpha - \dot{V}<em>O, ) Ht, ( \dot{S}</em>{\text{max}} )</td>
<td>0.82</td>
<td>0.68</td>
<td>3.4</td>
<td>( Y = 347.3 + 2.0(W \alpha - \dot{V}<em>O) - 0.27(Ht) - 1.24(S</em>{\text{max}}) )</td>
</tr>
</tbody>
</table>

\( Y \) = Performance in sec.

Freestyle performance and height was reinforced up to 0.75 (p < 0.01) while armspan and power became significantly correlated with performance in 100 m \((r = 0.66, \ p < 0.01\) and \(r = 0.58, \ p < 0.05\) respectively). The same analysis, however, did not equally augment the correlation between these variables and the performance in middle distance swimming.

Simple and multiple regression equations for predicting performance in 400 m freestyle swimming are also presented in Table 5. In the final model \( \dot{S}_{\text{max}} \), height and \( W \alpha - \dot{V}_O \), explain 68% of the performance variation.

Discussion

The results of this study demonstrate that it is possible to predict short (100 m) and middle (400 m) distance swimming performances with an overall accuracy of ±1.8 and ±1.3%, respectively. However, the final variable combinations cannot explain more than 70% of the variation in both the 100 m and 400 m crawl performances. On the other hand, as was expected, the factors which determine the performance level in short and middle distance swimming events are not exactly the same. Armspan and swimming power are important for predicting performance in 100 m swimming whereas the inclusion of submaximal weight-adjusted \( \dot{V}_O \), which represent the swimming economy improves the predictive power for the group of 400 m freestyle swimming \((r = 0.82, \ \text{SEE} = 3.4)\).

The most recent investigations that have studied the possibility to predict swimming performance, have reported stronger correlations. Costil et al (7) in an effort to judge which factors dictate success in middle distance swimming (e.g. 365.8 m crawl) in competitive collegiate swimmers, found that the combination of distance per stroke and \( \dot{V}_{O,\text{max}} \) (ml kg \(^{-1}\) min \(^{-1}\)) correlated 0.97 with performance. Furthermore, Cazorla and Montpetit (1) have measured international level swimmers and found a different but a strong correlation as well for predicting performance in middle distance swimming (300 m crawl). The combination of \( \dot{V}_{O,\text{max}} \) (1 min \(^{-1}\)) and swimming economy (\( \dot{V}_O \) at 1.1 m s \(^{-1}\)) correlated 0.86 with performance and the standard error was of the order of only 3.0 for 300 m swimming. Submaximal oxygen costs, adjusted for body mass, in combination with absolute \( \dot{V}_{O,\text{max}} \) could also explain up to 78% of the variation in the maximal average speed for 400 m swim attained by backstrokers of senior National competitive level served as subject in the study by Smith et al (23), and thus, in combination, highly indicative of performance ability. However, these two variables accounted only for 52% of the variance in reported times for 200 m backstroke races, and 67% of the variance in 100 m backstroke race times.

\( \dot{V}_{O,\text{max}} \) and performance

The inclusion \( \dot{V}_{O,\text{max}} \) in the regression equations for predicting the performance in middle-distance swimming is generally demonstrated as significant (1, 2, 7, 23). However, Van Handel et al (26) have shown that although \( \dot{V}_{O,\text{max}} \) was significantly correlated with 400 m freestyle competition time in competitive swimmers \((r = 0.62, \ p < 0.005)\), only 38% of the variance in performance could be explained by this variable. Additionally, in the same study if male and female swimmers are considered separately, no relationship existed between performance and \( \dot{V}_{O,\text{max}} \).

In the present study \( \dot{V}_{O,\text{max}} \) did not present a strong relation with performance for both groups. This factor was not even included in any of the final equations. Hence, it appears that \( \dot{V}_{O,\text{max}} \) does not have much predictive power for middle distance swimming perform-
Physiological and Physical Correlates of Swimming Performance

Swimming economy
The mean $W_{AI} - V_{O_2}$ at 1.3 m s$^{-1}$ for short and middle distance swimmers were not significantly different from each other. However, $W_{AI} - V_{O_2}$ was an important factor for predicting only the 400 m performance. This seems to be in agreement with Smith et al (23) who found a trend for the relative importance of $W_{AI} - V_{O_2}$ to decrease with decrease race distances in backstroke swimming. Thus, including $W_{AI} - V_{O_2}$ at a velocity of 1.3 m s$^{-1}$ improves the predictive power for the middle-distance group. The multiple correlation coefficient increased to 0.82 and the standard error for predicting the performance was reduced to 3.4 ($\pm$ 1.3%) even if the same variable alone is not significantly correlated with the 400 m crawl performance ($r = 0.10$). In a similar way, the results reported by Cazorla and Montpetit (1) did not show any correlation between performance and $V_{O_2}$ at a common velocity of 1.1 m s$^{-1}$ ($r = 0.20$) but this variable was included in the equation of predicting 300 m crawl performance ($R = 0.86$).

Oxygen consumption at submaximal velocities has been shown to be a considerable single predictor ($p < 0.05$) of competition time in middle distance swimming in several other studies (1, 7, 23, 26). In the study by Van Handel et al (26) swimming economy was found to be such a strong predictor of the 400 m freestyle performance that even the addition of $V_{O_2 max}$ lactic acid economy and maximal blood lactic acid did not further increase the power of the prediction.

The importance of physical variables
The combination of two physical variables, height and armspan, can explain up to 56% of the total variance in 100 m crawl performance. This is in agreement with previous observations that height and armspan are related to the sprint swimming performance (9, 11). However, the authors failed to separate the effect of armspan from that of height. The present results clearly show that keeping height constant makes the correlation between armspan and sprint performance significant.

The reasons why height is advantageous not only for 100 m but also for 400 m freestyle swimming, are easily explained. Firstly, from hydrodynamics theory it can be demonstrated that at the same speed a taller individual requires less power than a smaller person to advance in water (15, 20). Secondly, additional advantages of height in swimming is derived from the greater distance covered by the limbs during a stroke (15, 25). This sec-

ond consideration may also explain the importance of the armspan in the 100 m equation.

Stroke characteristics
An effect of stroke variables have been shown on energy cost of swimming (2, 7, 17). Slower and longer strokes seem to be a characteristic of elite swimmers (8, 24, 25). Craig et al (8) indicated that the finalists in all of the men’s freestyle events during the U.S. Olympic Swimming Trials in 1984, used slower stroke rates and achieved greater distances per stroke than the less successful swimmers. These data are in accordance with the negative high correlation observed between $S_{max}$ and 400 m performance in this study.

Swimming Power and sprint swimming
A number of studies have demonstrated a close relationship between biokinetic strength and sprint swimming performance (5, 13, 22). The advantage of this type of testing is believed to be its specificity to actual freestyle stroke mechanics. When using an accommodating resistance device on land, movement velocity is held constant at a preset value throughout a specified range of motion and there can be no limb acceleration. When this device is attached to a swimmer as we have done, the whole body velocity is constant, i.e. the swimmer moves at a preset value, but the arms are not subject to this limitation and thus the limb pattern can be similar to that of free swimming. The subject can develop optimal voluntary power for that speed without altering the range of motion of the limbs nor the pattern of acceleration.

Accommodating-resistance exercise has been shown to be a very effective mode of training for improved power (16, 21). Costill et al (6) reported a significant correlation between swimming power as associated with biokinetic swim bench and freestyle sprinting performance ($r = 0.62$). At the same time, the authors used this testing system to plot the changes in swimming power with training. They noted that throughout the season, “swimming” power changes in proportion to improvements or decrements in performance. Christensen and Smith (3) also suggest that sprint speed is related to the stroking force a swimmer can generate.

The data of the present study demonstrate a significant partial correlation between swim power and 100 m swimming performance ($r = 0.58$) with height, armspan, $v_{max}$ and $S_{max}$ held constant. In addition, swimming power was the only significant difference ($p < 0.05$) between the sprinters and the 400 m swimmers. However, the qualities that determine success in 100 m sprint freestyle swimming are based on more than just power. The combined use of swimming power and $S_{max}$ in the model for predicting 100 m performance increas-
ed the correlation to 0.84 and reduced the standard error to ±1.03.

Conclusions
In summary, these results suggest that:
1. The 100 m crawl swimmers are not generally different physically, functionally or from a metabolic standpoint from those of 400 m but the factors influencing performance in these two events are not exactly the same.
2. The best predictor variables for the 100 m swimmers were: height, arm span, swimming power and maximal stroke rate. The regression equation which contain the above variables may explain up to 71% of the variance in 100 m freestyle performance.
3. Knowledge of $S_{max}$ and height may explain 57% of the variance in performance for competitive middle-distance swimming. The addition of size-adjusted swimming economy to the above variables, can help to explain an even greater portion (almost 70%) of the variance in 400 m freestyle performance.

References
Force-Time and Electromyographic Characteristics of Arm Shoulder Muscles in Explosive Type Force Production in Sprint Swimmers

Dieter Strass
Institute for Sport and Sport Science, University of Freiburg, 7800 Freiburg, Schwarzwaldstr. 175 (F.R.G.)

Abstract

Based on the assumption that the explosive strength ability of the arm shoulder muscles is an influential factor on the sprint performance, 41 (group 1) and 17 (group 2) sprint swimmers carried out maximal voluntary contractions in three transient positions relevant to arm stroke motion with a special testing apparatus in the laboratory. Additionally, neuromuscular activity of selected muscle was studied at athletes of group 2. In the force-time (f-t) curve from each testing position the greatest slope (maximal rate of force development; RFD) and the maximal amplitude (maximal force; FMAX) was analyzed. To evaluate possible relationships between f-t characteristics and kinematic parameters (mean velocity; mean stroke frequency; mean stroke distance) of sprint performance, the athletes swam 50 m front crawl with maximal speed. For assessment the neuromuscular activity electromyographic (EMG) analyses of the muscles (m. pectoralis; m. deltoideus; m. teres major; m. latissimus; m. triceps; m. biceps) were conducted. The strength measurements showed on an average for FMAX in pos. 1 the highest and in pos. 3 the lowest values (p ≤ 0.05), and for RFD in pos. 1 the lowest and in pos. 3 the highest values (p ≤ 0.05). The correlations between f-t characteristics and swimming variables are only on an average level, but in general significant (p ≤ 0.05). The multiple regressions between these variables showed that the variance is in mean 20%, which corresponds to multiple correlation coefficient between R = 0.38 and R = 0.50. The averaged f-t-curves and EMG patterns of the investigated muscles are inter- and intraindividually different with regard to the rate of rises and maximal levels. The results suggest that good sprinters are better able to activate (recruitment and/or discharge frequency of motor units) the arm shoulder muscles compared to swimmers with little sprint performance. Probably sprinters with relatively high explosive strength level can produce higher impulses (propulsive efficiency) during the different phases in the arm stroke motion.

Introduction

In sprint swimming the athlete has to overcome with his arm-shoulder muscles motion high resistances with relatively fast speed during the underwater. Thus the single phases of the arm stroke may play a decisive role in relation to its propulsive efficiency. The analysis of force-time (f-t)- curves (9,14,15) have shown that swimmers need about 600 to 700 ms to exert maximal force during the whole arm stroke, but for the insweep phase only 150 to 200 ms. The explanation for this is the possible failure to develop a relatively high force in a short time interval (impulse). Thus, the athlete is not able to produce his optimal strength potential in this phase, which would be necessary. The earlier the swimmer can develop his maximal force, the more effective he can realize the downsweep and the insweep phase. However, this requires an adequate level of explosive strength, which depends on the optimal neuromuscular activation of the arm-shoulder muscles.

Explosive strength is defined as the ability to develop high force values in short time intervals (16). The explosive strength can be calculated in f-t-curves during isometric and dynamic concentric contractions with the parameters maximal rate of force development (RFD) and maximal force production (FMAX) (16,21). The explosive strength level is influenced on the neuronal side by the innervation (recruitment and frequency) of motor units (16,21) and on the muscular side by the hypertrophy (11) and the fiber composition (6). Explosive strength ability of the arm-shoulder muscles may be an important influential factor on the sprint performance of a swimmer. However, as far as we know little scientific evidence exists on an empirical basis. Previous studies primarily dealt with the relationships between...
maximal strength and sprint performance (3,10).

The aim of this investigation was to examine the explosive strength ability and the neuromuscular activity of selected arm-shoulder muscles of sprinters in technical positions relevant to swimming with a special testing apparatus in the laboratory. In addition it was to be evaluated, whether there are relationships between f-t-characteristics (RFD; FMAX) and kinematic parameters of swimming sprint performance.

Materials and Methods

Subjects. During the first part of the investigation the explosive strength ability of the arm-shoulder muscles of 41 (28 male, 13 female; subject group 1) sprint swimmers was analysed. Eleven subjects were members of the third class of the German Swimming Association (DSV), one swimmer ranged as 15th on the record list (DSV) in 50 m front crawl stroke, twenty actives were members of two teams in the second national class, nine subjects were sport students, who participated in the special course swimming at our university.

During the second part of the investigation the explosive strength ability together with neuromuscular activity of selected arm-shoulder muscles on 17 male sprint swimmers (subject group 2) was studied. Two athletes were members of the second national class from Switzerland, nine actives of the third national class of the DSV, one swimmer of the sport corps in Warendorf (F.R.G.), and five sport students who participated in the special course swimming at our university. Table 1 shows the mean values and the standard deviations of the physical characteristics of subject of both groups.

Testing apparatus. To examine the explosive strength level of the arm-shoulder muscles especially of swimmers, a new testing apparatus was constructed, which had to meet the following requirements:

(1) The measurements should be carried out under biomechanical (e.g. leverage) conditions; that is, for each subject all conditions have to be identical. The tests should exclude influences of intermuscular coordination. The results should be reproducible.

(2) With realistic identity as possible, the tests should be in accordance with the motions (down sweep—, insweep— and upsweep phase) of the arm stroke in the water. Great consideration should be given to high elbow position and the different positions of flexion in the elbow- and shoulder joint, respectively, for each test position.

(3) The force measurements in fixed positions should be realized by these muscles, which are involved in the arm stroke in water.

With regard to these factors the author developed with a company (GERMANIA, Landau; F.R.G.) a specific testing apparatus for swimmers, which allowed measurements of explosive strength levels of the arm-

<table>
<thead>
<tr>
<th>Physical characteristics (mean, SD) of the subject group 1 and 2.</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Subject group 1 (n = 41)</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Age (Years)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Figure 1.
The arm - shoulder strength test apparatus for swimmers in three measurement positions.
shoulder muscles in technic relevant positions (at the beginning of each main phase), first in isometric conditions (fig. 1). A horizontal lying steel barbell (length 100 cm, diameter 3 cm) has been fixed screwed tightly to the apparatus. On both sides are two plates. The left plate is of wooden material; the right plate is of aluminium (each 50 x 15 cm). The aluminium plate is the force plate. Between the plates (left and right side) and the steel barbell a rotation plate guarantees that each subject reaches the requested joint position of the upper and lower arm for each measurement position. The force plate consists of two aluminium plates, which lies on top of each other. Between these plates four one-dimensional force-transducers based on piezoelectric transducers by means of quartz discs (KISTLER) are fixed.

During the tests the subject is kneeling on a high-positioned seat. The hip and upper body are straight and the testee faces to the test apparatus. The upper arms are lateral extended and rotated inwards. The lower arms are also rotated inwards, the hands are pronated and are lying on the plates. A padded board, changeable in distance and slope to the apparatus, prevents the body from falling forward. To keep testee from elevating, the upper body is stabilized by shoulder paddings. Belts prevent the body from moving backwards and the lower arms and hands from sliding of the plates.

Testing. After an individual warming-up program the subjects carried out three maximal isometric contractions with their arm-shoulder muscles in three different positions. For statistics the arithmetic means of three trials for each position were calculated. To examine the reliability, tests (identical conditions for the angle positions of upper body-upper arm-lower arm/hand) were conducted twice over the period 15 days (test-retest-method). In position 1 the angle between upper body/upper arm and between upper-/lower arm was always 130°, in position 2 90° and 120°, respectively, and in position 3 80° and 120°, respectively (fig. 1).

The signals of piezoelectric transduction were amplified and transferred to a personal computer (IBM compatible). First the signals were digitally converted (sample frequency 250 Hz) and analyzed with the help of a special software program (12). In the f-t analysis the greatest slope (maximal rate of force development; RFD) and the maximal amplitude (Maximal force; FMAX) were analyzed (16). To find out possible relationships between explosive strength level and sprint performance the subjects carried out additionally 50 m front crawl tests with maximal speed. Kinematic parameters as mean velocity (Vs; m/s; mean stroke frequency (MF; 1/min), mean stroke length (Lx; m) and time for one arm stroke (T; s) were analysed with a normal watch and a special stroke frequency watch (HANHART). This special watch is calibrated by four arm cycles. The stroke length was derived from the equation: Lx = x (Vs x 60)/MF.

Electromyography. Electromyographic activity (EMG) of the selected right arm-shoulder muscles (m. pectoralis major (PM); M. Deltoides pars clavicularis (DC); M. teres major (TM); M. latissimus dorsi (LD); M. triceps br. caput laterale (TL); M. biceps brachii (BB)) was recorded of swimmers from subject group 2. In temporal and sequential process, these muscles are activated in different order during the arm stroke motion in water (2). Therefore EMG or PM, DC, TM and LD were recorded in position 1 and 2, in position 3 the EMG of the muscles TM, LD, TL and BB were recorded. To measure the EMG signals bipolar (20 mm inter-electrode distance) Ag/Cl-electrodes (BECKMANN miniature skin electrodes) were employed. The pairs of electrodes were fixed over the belly points of the muscles in accordance with the recommendations for surface EMG (7). The transfer of EMG-signals at two pairs of electrodes was carried out by one preamplifier (GLONNER).

Using telemetry equipment (BIOMES 80) the EMG-signals were sent to amplifiers. After converting (A/D-Converter; 300 Hz) the EMG and the force signals were transferred on a personal computer (VICTOR SIRIUS). With a specific program QUINTERN, Freiburg) all EMG-signals could be inverted and with a force threshold trigger over six contractions summed up and averaged.

Statistical methods. Ordinary statistical methods for calculating mean (x), standard deviation (s), coefficient of correlation (PEARSON, r) and multiple regression (R) were used. The statistical differences between the variables of explosive strength ability of both test days were examined for significance by using the Student's t-tests (one tailed for dependent) and non parametric tests (Mann Whitney- matched- pairs signed- ranks test).

Depending on the sprint performance subgroups (G1; 50 m x < 28.6 s; G2; 28.6 s < x < 29.6; G3; x > 29.5 s) were formed. To examine possible differences in group mean values of f-t characteristics one way analyses were conducted. The levels of significance were set at p ≥ 0.05 not significant, p ≤ 0.05 (*) and p≤0.01 significant (**).

Results
Reliabilities
Table 2 and 3 show reliability coefficients of f-t variables (maximal force production (FMAX)) and maximal rate of force development (RFD) for the three positions of two testing days. All coefficient values are relatively high. By dividing the subject group 1 up into three subgroups, depending on sprint performance (G1; G2; G3), reliabilities between rfit = 0.74 and rfit = 0.94 are observed.
Table 2.
Mean, SD, t-values (one tailed for depended test, * = p ≤ 0.05, ** = p ≤ 0.01), z-values (Mann Whitney) and coefficients of correlations ($r_{pb}$) for the values of Rate of force development in three positions from two testing days (subject group 1).

<table>
<thead>
<tr>
<th>Positions</th>
<th>Rate of force development [N/ms]</th>
<th>t-value (z-value)</th>
<th>$r_{pb}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. pos.</td>
<td>1.51 (0.73)</td>
<td>-1.11 (-1.45)</td>
<td>0.84**</td>
</tr>
<tr>
<td>2. pos.</td>
<td>1.47 (0.73)</td>
<td>-1.67 (-1.33)</td>
<td>0.74**</td>
</tr>
<tr>
<td>3. pos.</td>
<td>1.50 (0.76)</td>
<td>-2.91* (-2.47)*</td>
<td>0.76**</td>
</tr>
</tbody>
</table>

Relationships between the measurement positions

<table>
<thead>
<tr>
<th>correlation coefficients</th>
<th>1./2. pos.</th>
<th>1./3. pos.</th>
<th>2./3. pos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1./2. pos.</td>
<td>0.81**</td>
<td>0.86**</td>
<td>0.81**</td>
</tr>
<tr>
<td>1./3. pos.</td>
<td>0.72**</td>
<td>0.85**</td>
<td>0.83**</td>
</tr>
<tr>
<td>2./3. pos.</td>
<td>0.83**</td>
<td>0.87**</td>
<td>0.85**</td>
</tr>
</tbody>
</table>

Force-time and swimming variables

In trend the subjects produce on an average for (FMAX) in position 1 the highest and in position 3 the lowest values (tab. 2). The differences are significant (p ≤ 0.05). The values from the second testing day are on higher levels compared to the first day. For position 1 the differences are not significant, however for positions 2 and 3 they are significant (p ≤ 0.01). The values for (RFD) on the second testing day are on higher levels in comparison to the first day (tab. 3). For position 3 the differences in the mean are significant (p ≤ 0.05), no differences are observed for position 1 and position 2. The numeric height of the standard deviations indicate that in relating to individual cases, there are great differences in the f-t variables for each test position. Table 4 shows the values for kinematic parameters of the swimming performance of the subject group 1 and their subgroups. It has to be noted that due to illness the subject group was reduced from n = 41 to n = 37. The differences in sprint performance between the three subgroups are obviously: G1 is on average 0.10 m/s faster than G2 (5.5 percent) and 0.33 m/s faster than G3 (18.1 percent); G2 is 0.23 m/s faster than G1 (13.3 percent).

Explosive strength level and spring performance

The correlations between (RFD) and (FMAX) from the second testing day, and swimming variables (Vs, MF, Lx) for subject group 1 and their subgroups (G1; G2; G3) are listed in tab. 5. For the whole group the coefficient values are only on an average level, however, they are in general significant. The corresponding correlations for the subgroup (G1) are higher compared to the others (G2; G3). Between the f-t variables and the swimming variables, only little or no correlations have been observed.

By means of multiple regressions the relationships between f-t variables (RFD; FMAX) and sprint performance (Vs) can be estimated. The results are shown in tab. 6. For the whole group the variance of f-t values and swimming characteristics is in mean 20%, which corresponds to multiple correlation coefficient between R = 0.38 and R = 0.50. A closer relationship can be found for the best subgroup (G1). Here, the variances are between 27 and 53%, which corresponds to coefficient values between R = 0.52 and R = 0.73. The relationship between explosive strength level and swimming sprint performance are decreased (G2; G3).

Table 4.
Mean and SD of the sprint performance variables (subject group 1).

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Subject group (n=37)</th>
<th>x &lt; 28.6 s (n=10)</th>
<th>28.55s &lt; x &lt; 29.65s (n=11)</th>
<th>x &gt; 29.5 s (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>x</td>
<td>s</td>
<td>x</td>
</tr>
<tr>
<td>mean velocity (50 m)</td>
<td>m/s</td>
<td>1.6</td>
<td>0.16</td>
<td>1.83</td>
</tr>
<tr>
<td>mean stroke frequency</td>
<td>f/min</td>
<td>47.65</td>
<td>4.54</td>
<td>49.90</td>
</tr>
<tr>
<td>mean stroke length</td>
<td>cm</td>
<td>209.89</td>
<td>18.75</td>
<td>220.70</td>
</tr>
<tr>
<td>mean stroke time (1 arm stroke)</td>
<td>s</td>
<td>0.64</td>
<td>0.06</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Table 5.
Coefficient of correlation of relationships between explosive strength characteristics (FMAX, RFD) and kinematic variables of swimming for subject group 1 and their subgroups (G1; G2; G3).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Subject group 1 (n = 41)</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VS</td>
<td>MF</td>
<td>Lx</td>
<td>VS</td>
</tr>
<tr>
<td>FMAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>position 1</td>
<td>0.49*</td>
<td>0.21</td>
<td>0.26</td>
<td>0.68</td>
</tr>
<tr>
<td>position 2</td>
<td>0.41*</td>
<td>0.17</td>
<td>0.21</td>
<td>0.38</td>
</tr>
<tr>
<td>position 3</td>
<td>0.51**</td>
<td>0.16</td>
<td>0.32</td>
<td>0.37</td>
</tr>
<tr>
<td>RFD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>position 1</td>
<td>0.44*</td>
<td>0.32</td>
<td>0.08</td>
<td>0.71*</td>
</tr>
<tr>
<td>position 2</td>
<td>0.37</td>
<td>0.20</td>
<td>0.13</td>
<td>0.34</td>
</tr>
<tr>
<td>position 3</td>
<td>0.50**</td>
<td>0.16</td>
<td>0.31</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Characteristics of the second testing day are listed in Table 7. The group means for FMAX show significant differences between the subgroups. The group mean values for RFD in position 3 is significantly different between the subgroups, but not for the corresponding values of position 1 and 2.

EMG- and Force-time curves
The results on EMG of selected arm-shoulder muscles at maximal contractions are based on averaged EMG patterns for members of subject group 2. Pretests have shown that EMGs of PM and DC in position 3 show only little activities. Therefore, these muscles have not been taken into account in this study. The EMG profiles of the muscles (PM, DC, TM, LD; position 1 and 2) and (TM, LD, TL, BB; position 3), are inter- and intra-individually different. Fig. 2 and 3 illustrate averaged EMGs of these muscles and the recordings of averaged force-time curves as typical examples of swimmers with differences in explosive strength level and sprint performance. The subject group 2 swim during the period of strength tests in the 50 m front crawl 24.9 s. The single EMG patterns of this subject show relatively steep slopes. The f-t curves also illustrate relatively steep rates of rise and high maxima. Different observations with respect to averaged EMG- and f-t curves have been made on subject 11. The single EMG profiles show relatively flat slopes and low levels. The f-t curves also are characterized by flat rates of rise and low maxima. The sprint performance of this subject was during the period of strength tests 28.1 s in the 50 m front crawl.

Since the intensity of the EMG signals is influenced by numerous factors, such as thickness of the subcutaneous fat tissue, transitional resistance of the skin to the electrodes and so on, the absolute increases and the maxima can not be taken into consideration when compar-

Table 7.
Mean, SD, F-values for force-time characteristics (RFD, FMAX) of the subgroups (G1; G2; G3).

<table>
<thead>
<tr>
<th></th>
<th>G1 (n=10)</th>
<th>G2 (n=11)</th>
<th>G3 (n=10)</th>
<th>F-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMAX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>position 1</td>
<td>225.4 (52.6)</td>
<td>202.1 (68.4)</td>
<td>159.9 (51.4)</td>
<td>3.418</td>
<td>0.05</td>
</tr>
<tr>
<td>position 2</td>
<td>218.5 (58.7)</td>
<td>199.2 (82.8)</td>
<td>157.4 (48.9)</td>
<td>3.208</td>
<td>0.03</td>
</tr>
<tr>
<td>position 3</td>
<td>216.9 (53.0)</td>
<td>191.6 (59.7)</td>
<td>144.3 (47.1)</td>
<td>6.649</td>
<td>0.01</td>
</tr>
<tr>
<td>RFD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>position 1</td>
<td>1.91 (0.50)</td>
<td>1.73 (0.82)</td>
<td>1.27 (0.54)</td>
<td>2.656</td>
<td>n.s.</td>
</tr>
<tr>
<td>position 2</td>
<td>1.95 (0.69)</td>
<td>1.82 (0.99)</td>
<td>1.29 (0.55)</td>
<td>2.767</td>
<td>n.s.</td>
</tr>
<tr>
<td>position 3</td>
<td>2.03 (0.76)</td>
<td>2.05 (0.69)</td>
<td>1.32 (0.67)</td>
<td>5.733</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 6.
Multiple coefficients of correlation on relationships between force-time characteristics (FMAX, RFD) and mean swimming speed (50 m front crawl stroke) for subject group 1 and their subgroups (G1; G2; G3).

<table>
<thead>
<tr>
<th></th>
<th>Subject group 1 (n=41)</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>R1</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>

1. test day
position 1 | .44898 | .20155 | .80670 | .65076 | .34581 | .11959 | .35140 | .12348 |
position 2 | .33423 | .12549 | .64156 | .41159 | .66834 | .44668 | .05912 | .00559 |
position 3 | .41816 | .17486 | .54073 | .29239 | .37482 | .14049 | .53951 | .29107 |

2. test day
position 1 | .45249 | .21389 | .73305 | .52737 | .54247 | .29428 | .30993 | .09605 |
position 2 | .38573 | .14878 | .52057 | .27100 | .50896 | .25904 | .16602 | .02756 |
position 3 | .50741 | .25747 | .57994 | .33633 | .24429 | .05968 | .13392 | .01793 |
Figure 2.
Example of EMGs (n = 6) of selected arm - shoulder muscles and force-time curves of maximal contractions in three measurement positions of one subject with relatively good sprint performance.

The relative rates of rise in the EMG profile have greater slope than for subject 11.
Remarkable are the interindividual different EMG-profiles of the arm muscles (TL and BB) in position 3 (fig. 2 and 3). For subject 2, the EMG pattern of TL show a relatively high level in comparison to BB. On

Figure 3.
Example of EMGs (n = 6) of selected arm - shoulder muscles and force-time curves of maximal contractions in three measurement positions of one subject with relatively less sprint performance.
the other hand, for subject 11 a higher level can be seen in EMG of BB against TL.

Discussion
The reliability coefficients for f-t variables of both testing days are for FMAX between \( r_n = 0.85 \) and \( r_n = 0.91 \) and for RFD between \( r_n = 0.74 \) and \( r_n = 0.84 \). The comparison of these results with statements in literature indicate, that all coefficient values may be interpreted as acceptable to excellent. Thus, one can expect that the results at further tests with this apparatus will be reliable.

To explain the values of FMAX and RFD from the three testing positions, first mechanical factors of the muscles have to be taken into consideration. Especially, the levers of force arm and resistance arm (hand, lower-and upper arm) may play a decisive role. Additionally to leverage, the measurement of explosive strength ability of arm-shoulder-muscles in present test conditions is determined by the force-length relation (dependence on the force production of the muscle from the shortening velocity). However, estimating the influence of these factors on the FMAX and RFD values is difficult.

The observations of the averaged EMG- and f-t curves (fig. 2 and 3) are in agreement with the results of basic research in strength area (6,16). They reported, that subjects with relatively high explosive strength levels show simultaneous steep slopes in averaged EMG-patterns (in regard to the relative rate of rise), whereas untrained subjects show flat slopes in their EMG profiles. This phenomenon was explained with differences in motor unit recruitment and motor unit firing rate. These mechanisms may play also a role in the EMG pattern of subject 2 compared to those of subject 11, which could lead to a higher explosive strength level. It is possible that subject 2 has a faster neuronal activation than subject 11.

Fig. 2 and 3 illustrate that swimmers produce maximal force in about 700 ms. These observations are in relation to reports of force-time analyses in swimming (9,15,16). Beside maximal force production, maximal rate of force development may play an important role during insweep phase in arm stroke, mainly in regard to the propulsive efficiency. Subject 2 realized a relatively high RFD value. Based on this, he can probably produce during swimming a relatively high impulse in each arm stroke. The swimming speed over 50 m front crawl confirmed this hypothesis. On the other hand subject 11 reached a relatively low value of RFD. Maybe this fact affects the quality of the arm stroke in swimming. The swimming time of subject 11 supports this opinion.

Surprising are the interindividual different EMG profiles of triceps muscles (TB) and biceps muscle (BB) in testing position 3. This was typical for swimmers with differences in explosive strength ability and sprint performance. These observations may be associated with co-contraction; i.e. simultaneous contraction of agonist (TB) and antagonist (BB). The co-contraction of the antagonist is especially intensive when the contraction of the agonist strong and rapid is (4, 18), or, when subjects are untrained in the testing task (13). This phenomenon could apply to subject 11, although this subject performed the same testing task at least 10 times during the first study. However, it has been suggested, that co-contraction of the antagonist may provide a protective mechanism during relatively rapid and strong neuronal activation of agonists (20). Co-contraction of the antagonists impairs by reciprocal inhibition, the ability to fully activate the agonists, as indicated by reduced IEMG and motor unit firing rates in maximal voluntary contractions (5, 20).

Relationships between f-t- and swimming characteristics
The numeric height of relationships between maximal force level (FMAX) and spring speed (Vs) for homogenous groups are in good agreement with the previous results (3,10,19). It can be concluded, that better sprinters are better able to produce high maximal forces. The analysis of correlations shows further that there are relationships between the maximal rate of force development (RFD) and sprint performance (Vs).

The results of multiple regression analyses extend the above conclusion. With all caution in regard to causal relationships the corresponding results indicate, that explosive strength ability of swimmers at least partly affect their sprint performance. However, the hypothesis, that these results are also valid for more homogeneous athletes on higher sprint levels should be examined in further investigations at sprint swimmers of national A- and B- teams.

Conclusions
In swimming practice the arm strength abilities of athletes is estimated by mean of isokinetic strength training machines (e.g. biokinetic swim bench). These apparatus allow a mechanical change of resistance depending on the joint angle, whereby the speed in the whole arm motion can be kept constant (relatively slow). These strength training machines can be linked to a computer. Thus one can record force curves and register for each athlete the time for maximal force production. Using this control procedure, kinematic and dynamic outside criteria are given. The advantages are, that by imitating the kinematic motion of the conditions in water the maximal force values can be measured, which are typical for the arm stroke movement. However, during these imitated arm movements the surveyor of the shoulder and elbow joint are constantly changing, which affect the levers of the involved musculature. It is further thought, that the time process of isokinetic ap-
paratus with maximal force production at the end of
the arm motion is not the same as it is in swimming.
It would be incorrect to say that the muscles are work-
ing smoothly because the arm movement, as seen from
the outside, is moving at an even place (8). A further
problem in this test procedure for assessing strength
abilities, is the failure to control the elbow position (the
elbow should always be above the hand). Thus the reli-
bility of diagnostic findings is relatively susceptible
to inaccuracy.

The decisive advantage of the testing apparatus used
in this investigation is, to be able to receive exact values
based on standardized and reproducible conditions on
actual explosive strength level (intermuscular coordina-
tion of muscles, which are relevant for swimming tech-
tniques). By inter- and intraindividual comparison such
individual strength diagnostic can show the failures to
arm-shoulder musculature, especially on sprint swim-
mers. When electromyography is used in addition to
strength diagnostic, the activity (onset, slope, duration)
of the involved muscles can be determined, imitating
the positions of main phases of arm stroke. Such a deter-
mination is important for coaches and athletes, if they
want to carry out analyses of coordination related to
the output of muscular force.

Finally, to note, that at this time the testing apparatus
used for estimating strength abilities is modified for
dynamic-concentric contractions at cyclical arm
movements. Thus this apparatus can be applied to
strength training.

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Summary
Based on the assumption that the explosive strength
ability of the arm shoulder muscles is an influential fac-
tor on the sprint performance, 41 (group 1) and 17
(group 2) swimmers performed isometric maximal con-
tractions in three technical positions relevant to arm
stroke motion with a special testing apparatus in the
laboratory. Additionally neuromuscular activity of
selected muscle was studied at swimmers of group 2.
In the force-time (f-t) curve from each testing position
the greatest slope (maximal rate of force development; RFD) and the maximal amplitude (maximal force; FMAX) was analyzed. To evaluate possible relationships between f-t- characteristics and kinematic parameter (mean velocity; mean stroke frequency; mean stroke distance; time for one stroke) of sprint performance, the athletes swam 50 m front crawl with maximal speed. For assessment the neuromuscular activity electromyographic (EMG) analyses of the muscles (m. pectoralis; m. deltoideus; m. teres major; m. latissimus; m. triceps; m. biceps) were conducted. The strength measurements showed on an average for FMAX in pos. 1 the highest and in pos. 3 the lowest values (p ≤ 0.05), and for RFD in pos. 1 the lowest and in pos. 3 the highest values (p ≤ 0.05). The correlations between f-t-characteristics and swimming variables are only on an average level, but in general significant (p ≤ 0.05). The multiple regressions between these variables showed that the variance is in mean 20%, which corresponds to multiple correlation coefficient between R = 0.38 and R = 0.50. The averaged f-t-curves and EMG patterns of the investigated muscles are inter- intraindividually different with regard to the rate of rises and maximal levels. The results suggest that good sprinters are better able to activate (recruitment and/or discharge frequency of motor units) the arm shoulder muscles compared to swimmers with relatively little sprint performance. Probably sprinters with relatively high explosive strength level can produce higher impulses (propulsive efficiency) during the insweep phase in the arm stroke motion.
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Rib Dysfunction in Competitive Swimmers

JAMES G. GRIFFIN, M.ED., P.T., A.T.C.
Department of Anesthesiology, Pain Management Clinic, The University of Texas Health Science Center,
San Antonio, Texas, 78284-7838.

RALPH J. CURTIS, M.D.
Clinical Assistant Professor of Orthopedics, The University of Texas Health Science Center,
San Antonio, Texas, 78284-7838.

Abstract
Dysfunction of the first two ribs can be confused with or contribute to shoulder problems in competitive swimmers. This may occur as a primary problem or be associated multidirectional instability of the shoulder. The anatomy of the junction of the cervical spine, thoracic spine and first two ribs is complex and gives rise to several medical problems. Osteopathic physicians have developed a method of assessing and treating problems in this and other areas of the body. Individuals who complain of poorly defined, poorly localized shoulder pain may have only a dysfunction of the ribs. These individuals will have subjective and objective findings which will increased the index of suspicion. If a significant problem is suspected, the individual should be referred for medical evaluation. In many cases, rib dysfunction can be treated by the swimmer with simple stretching and isometric exercises and postural correction. More resistant problems may require treatment by a practitioner skilled in manual therapy. Three case studies are discussed. Recognition and early, conservative treatment of this problem can result in less expense and less training time lost to suspected shoulder problems which may not exist.

Introduction
Shoulder pain is the problem in swimming sports medicine (8). Most swimmers competing at the national level have had problems requiring some form of treatment including modifying training, stroke changes, remedial exercises, biceps tendon straps, ice, heat, medication, surgery or retiring from competitive swimming all together (1,2,5,9,15,16). The mechanics of the gleno-humeral joint and the impingement syndrome in competitive swimmers are well described by Kennedy and Hawkins (9), Richardson, (15), Richardson, et al (16), and Ciullo (5) and will be referred to but not reviewed here. The interested reader is directed to the aforementioned references.

It has been the observation of the authors that a common somatic dysfunction described in the osteopathic literature contributes to or is mistaken for shoulder impingement syndrome (3,7,13). Dysfunction of the first or second rib has been seen in many swimmers examined for shoulder pain over the last four years since we have begun looking for this entity. In many cases this was the cause of shoulder pain, as treating the rib dysfunction completely resolved the shoulder problem. Dysfunction of the first rib has also been seen to cause complaints of an unusual nature distal to the site of dysfunction which resolved with treatment of the dysfunction. Rib dysfunction may occur as a primary problem but seems to be associated with or secondary to multidirectional instability of the shoulders, a common finding in competitive swimmers.

Theoretical Models
The term "somatic dysfunction" refers to a loss of normal joint function without loss of joint congruity or disruption of the joint capsule. This term is synonymous with "joint blockage" or "joint subluxation" used by practitioners of manual medicine to describe the clinical observation of a joint which lacks normal motion when assessed passively and actively. The loss of normal motion is postulated to cause discomfort and dysfunction at or distal to the site of the problem (7). Several traditionally trained orthopedic physicians such as John Bourdillon (3), James Cyriax (6) and John Mennell (12) have published on the utility of this approach for specific orthopedic problems, and many physical therapists are beginning to use these techniques.
in their practice. The osteopathic profession has developed a model for specifically identifying and treating joint dysfunction throughout the body (13). It is from the osteopathic model that many of the techniques of diagnosis and treatment in this paper are taken.

Anatomy

The anatomy of the area of the joints between the first two ribs and the adjacent vertebrae is complex and filled with sensitive structures. The first rib is an atypical rib. It is the most curved and usually the shortest of the ribs. The head of the rib articulates with the first thoracic vertebra and an oval shaped facet on the tubercle of the rib articulates with the transverse process of the first thoracic vertebra. The first rib lacks the superior costotransverse ligament and intra-articular ligament found in typical ribs. The second rib is a typical rib with a large facet on the head attaching to the corresponding vertebra and a smaller facet articulating with the vertebra above. It also forms a joint with the transverse process of the second thoracic vertebra. The structure of the joints of the upper six ribs allows only slight gliding motion between the ribs, vertebral bodies and transverse processes which produces a small degree of rotation of the rib along its long axis. Upward rotation of the neck of the rib corresponds with elevation of the anterior end of the rib and its costal cartilage and downward rotation with depression of the anterior end of the rib and its cartilage, corresponding with inhaling and exhaling.

Attached to the first rib are the anterior and middle scalene muscles. The anterior scalene arises from the anterior tubercles of the third through sixth cervical vertebra and descends almost vertically to attach to the scalene tubercle on the superior surface of the first rib. The middle scalene is the largest of the scalene muscles and arises from the transverse process of the axis and the posterior tubercles of the transverse processes of the lower five cervical vertebra, attaching to the first rib posterior to the anterior scalene and separated from it by the subclavian artery and vein and the brachial pleus. The posterior scalene arises from the posterior tubercles of the transverse processes of the third, fourth, and fifth cervical vertebra and attaches to the superior and outer surface of the second rib. The scalenes, acting from below, sidebend the cervical spine at the level of attachment to the same side. With the neck stabilized, the scalenes elevate the ribs to which they are attached. The scalenes, especially the middle scalene, are active in inspiration, even during quiet breathing (17).

Symptoms

There are several problems recognized in medicine which are thought to originate in the area of the junction of the cervical spine, thoracic spine and first rib. Anterior scalene syndrome, clavicolosternal syndrome and pectoralis minor syndrome are described by Calliet (4) as resulting from compression of the neurovascular bundle as it passes from the cervical region into the shoulder and arm. These syndromes are described as causing pain in the shoulder, arm, or hand, and producing paresthesia (a feeling or tingling or "going to sleep") in the distribution of the ulnar nerve on the little finger side of the hand and forearm. Treatment consists of postural correction, specific stretching and strengthening exercises, and, as a last resort, removal of a cervical rib, if present. The contribution of abnormal function of the first rib to thoracic outlet syndrome (T.O.S.), a condition which is a collective term for the syndromes previously mentioned, is recognized by Lindgren and Leino (10), who report several case studies of thoracic outlet syndrome, resistant to other forms of treatment, being resolved by isometric self-mobilization of the first rib. In the manual medicine field, Lewit (11) and Phillips and Grieve (14) recognize rib dysfunction as a cause of pain which can be referred to the shoulder.

The possible dysfunctions of the rib cage are described in detail by Mitchell, Moran, and Pruzzo in their publication "An Evaluation and Treatment Manual of Osteopathic Muscle Energy Techniques" (13). These include restrictions of motion which inhibit inhalation or exhalation, posterior or anterior displacement of the ribs, torsional deformities, and, in the case of the first rib, superior displacement with either an anterior or posterior component. Most commonly seen by the authors in competitive swimmers is the superior and posterior displacement of the first rib and the posterior displacement of the second rib. With prolonged, deep respiration and vigorous neck and shoulder motion, it is not difficult to see how the scalene muscles could pull either of the first two ribs into a dysfunctional position. The side of the problem does not necessarily coincide with the breathing or non-breathing side in swimmers. Mild dysfunctions will normally resolve over time, as most minor problems do, but the dysfunction which does not resolve spontaneously and becomes symptomatic must be treated. As previously stated, rib dysfunction is often associated with impingement syndrome. Impingement must be assessed and treated if present. If no impingement is found, a rib dysfunction may be suspected if the swimmer is complaining of what he or she describes as "shoulder pain".

Individuals with this problem will often have complaints similar to those of impingement, but can be differentiated on the basis of subjective and objective findings. Subjectively the swimmer may complain of "shoulder pain", but will not be able to localize the complaint. When asked to put one finger where the pain is, the individual will indicate the whole shoulder and
up into the neck. The swimmer may complain of a stiff neck or a mild feeling of the medial forearm and little finger "going to sleep" or "feeling funny" (paresthesia). Discomfort may or may not be associated with training, using paddles or other specific activities. When viewed from above and behind, the swimmer may have a noticeable lack of cervical rotation to the affected side, and sidebending both towards and away from the affected side may be restricted and uncomfortable at the junction of the neck and shoulder. Palpation of the area of the angle of the first two ribs will be very tender on the side of involvement versus the uninvolved side (Figure 1); this is commonly mistaken for "muscle tightness" or a "trigger point" in the trapezius muscle. Palpation anteriorly of the joint between the rib and the sternum will also be very tender on the involved side (Figure 2). If done carefully and with a light touch, it is possible to discern a definite difference in muscle tone on the affected side, as well as a definite asymmetry of the rib angles posteriorly. Excursion of the ribs on the involved side may be different with forced inhalation and exhalation. The assessment of symmetry and motion is subtle and may not be observed by most individuals unless trained in palpation. For the coach who suspects a rib dysfunction in a swimmer, the major clues are: 1. subjective complaints of shoulder discomfort; 2. inability to localize shoulder pain; 3. tenderness with palpation of the rib angles posteriorly and the joint(s) between the rib(s) and sternum anteriorly; 4. motion restrictions of cervical rotation and sidebending with associated discomfort on the involved side and; 5. mild complaints of the hand or forearm "going to sleep" on the involved side. The swimmer may complain of only one of these symptoms; careful questioning and examination will usually reveal two or three more. Should a significant problem be suspected, refer the athlete for medical evaluation for the protection of all concerned.

**Treatment**

Conservative treatment of this problem can be done by the swimmer. The goals of treatment are to restore normal mobility to the dysfunctional rib and stretch the muscles involved. Mobility can be restored by having the swimmer perform a series of isometric exercises devised by Lindgren and Leino (10) in the treatment of
thoracic outlet syndrome. The swimmer performs a set of isometric exercises using the arm of the involved side to provide resistance to flexion (Figure 3), extension (Figure 4), and sidebending of the head (Figure 5) to the involve side. Each repetition is held for 1 second and repeated 10 times, 5 times daily. The scalene muscles are active in each of these exercises and will mobilize the upper two ribs, restoring normal motion.

Stretching of the anterior neck musculature is achieved by having the swimmer anchor the shoulder of the involved side using the opposite hand to pull downwards on the arm in front of the body. With the involved arm anchored in front of the body, the swimmer allows the head to fall back and to the opposite side, holding this position for 10 seconds (Figure 6). If done correctly, the individual will feel a stretch and almost a burning sensation in the front of the neck and just above the collarbone. Next, the arm is anchored at the side and the head allowed to fall directly to the opposite side (Figure 7), producing a stretch of the side of the neck into the shoulder. Finally, the arm is anchored behind the back on the involved side and the head allowed to fall forward and to the opposite side (Figure 8), producing a stretch along the posterior and lateral margin of the neck. These stretches should be repeated 3-5 times.
each, held for 10 seconds, and performed at least three times daily. Many prefer to stretch in a hot shower in the morning and prior to and after training. As with all stretching, these exercises should be done in a slow, controlled manner.

It may also be necessary to modify some of the swimmer’s activities until the discomfort subsides. Particular strokes or drills may increase the swimmer’s complaint, and weight training involving overhead activity, such as military press, may be provocative. Posture is an important consideration as well. Many young people (and adults) have an habitual posture of a rounded upper back, rounded shoulders, and forward head (1). Youth compensates for many errors, so the young have few of the chronic problems seen in adults who have been in this abnormal posture for years, but posture can contribute to rib dysfunction by allowing shortening and tightening of the scalenes. With decreased range of motion comes the risk that the muscle will lack adequate excursion and pull one of the first two ribs into dysfunction. An effort should be made to correct this by having the individual pull the shoulders back and tuck the chin. This will restore the normal cervical lordosis and keep the muscles attached to the occiput, cervical spine, and adjacent structures at a normal length. Poor posture also contributes to the true shoulder problems as well and should be corrected if at all possible (1).

When recognized and treated before allowed to become chronic, most rib dysfunctions respond to the above treatment in a few days to a week. Those which do not respond will require treatment by an individual skilled in manual medicine. Osteopathic physicians are trained in this area, as are more and more physical therapists. These individuals can assess the problem and provide appropriate treatment or refer the individual on if there appears to be something wrong other than a somatic dysfunction, a possibility which must always be kept in mind for the well-being of the swimmer. As with shoulder impingement problems, some individuals may be particularly prone to rib dysfunction problems. Special emphasis should be placed on such individuals’ posture and they should be on a prophylactic program of stretching and isometrics to prevent the problem from recurring.
Case Studies

1. A sixteen year old male Junior National qualifier was referred to one of the authors (J.G.) with complaints of right tricep pain. There had been no injury to the shoulder or arm. The swimmer complained of pain on the posterior aspect of the upper arm with swimming breaststroke and freestyle and doing tricep curls. Point tenderness could be elicited with palpation of the midtriceps, but no other maneuver caused pain. Reflex, motor and sensory tests of the upper extremities were normal and symmetrical. Cervical motion was slightly restricted to the right, but no peripheral discomfort was elicited with cervical or shoulder motion or combined motions of the two. Examination revealed a superior displacement of the right first rib, with only mild posterior tenderness and no referral of pain distally with vigorous palpation. The rib was manually mobilized with resolution of the swimmer’s complaints with activity and palpation by the next day.

2. A 17 year old female Junior National champion experienced recurring left shoulder pain with training. She had been treated with rest, heat and aspirin for a prior episode of shoulder pain with resolution of symptoms. When she returned to training she had several episodes of shoulder problems which included dull aching in the anterior shoulder which increased with yardage swim, posterior periscapular discomfort and paresthesia in the ulnar distribution. Orthopedic evaluation (R.C.) revealed multidirectional shoulder laxity with positive impingement signs. Evaluation of the cervicothoracic area by a physical therapist with manual medicine skills showed restriction of the left first rib and upper thoracic and lower cervical spine. Treatment consisted of moist heat, stretching for shoulder impingement and vigorous rotator cuff rehabilitation to stabilize the shoulder. Dysfunction in the cervico-thoracic area was treated with mobilization and stretching of the involved segments over a two week period. This athlete’s complaints resolved and she went on to compete in the 1988 Olympic Trials and was awarded a scholarship at an N.C.A.A. Division 1 school.

3. An eleven year old female age-group swimmer complained of right shoulder discomfort with swimming. The complaint was ill-defined and not associated with any specific injury. Her coach found tenderness at the posterior angle of the right first rib and anteriorly at the costosternal joint. The swimmer was instructed by her coach to stretch daily and in three days her complaints were gone and swimming was painless.

The first case illustrates the effect which a joint dysfunction can have distally. The nerve roots of the brachial plexus pass over the first rib as they exit the neck and pass down the posterior aspect of the arm as a part of the radial nerve (17). It is not difficult to see how a slight upward displacement of the rib might traction the nerve roots slightly and cause pain at a distal point where the radial nerve is tethered in soft tissue. The second case is an example of combined impingement and somatic dysfunction which both required treatment to allow optimal function. It must be emphasized that these treatments are complementary. Shoulder impingement and joint dysfunction frequently occur together so that the presence of one should arouse the suspicion of the other, especially when treatment of either entity singularly produces suboptimal results. In a sport where success is determined by hundredths of seconds it is important that all possibilities be considered when treating the athlete. The final case is the most common, with vague complaints of shoulder pain not associated with any specific incident, anterior and posterior rib tenderness, and quick resolution with stretching. Numerous cases similar to this one have occurred in the club team with which the authors work. Many of the coaches at the club now recognize this problem and have the swimmer begin stretching immediately at the swimmer’s first complaint. In most instances the problem resolves quickly with little training time lost and at a significant savings in time and money seeking medical treatment for an impingement syndrome which may not exist.

Summary

Dysfunction of the first two ribs can exist with or be confused with the shoulder impingement syndrome in competitive swimmers. This may occur as a primary problem or secondary to multidirectional instability of the shoulders. Rib dysfunction will present as vague shoulder discomfort not well-localized by the swimmer. On the involved side, the rib angles will be tender posteriorly, and the anterior joint with the sternum will be tender as well. There may be some restriction and discomfort with cervical motion and complaint of a mild paresthesia on the medical side of the forearm, hand, and in the little finger. Specific stretching of involved musculature, isometric exercise, and postural changes can resolve complaints of discomfort in a few days. When any doubt exists, refer the athlete for medical evaluation and treatment. Chronic problems may require treatment by a practitioner skilled in manual medicine. Rib dysfunction and shoulder impingement syndrome may occur together and will require treatment of both disorders to achieve optimal results. Individuals prone to rib dysfunction should watch their posture closely and be on a preventative stretching and exercise program to avoid recurrent problems.

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—AUTHOR GUIDELINES—
(Revised May, 1990)

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