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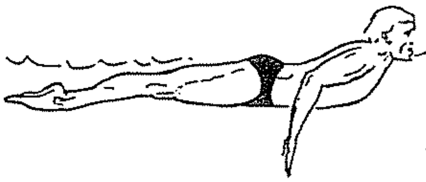

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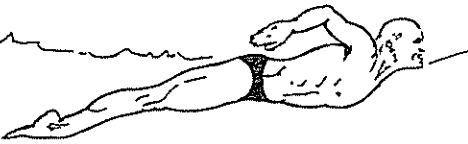

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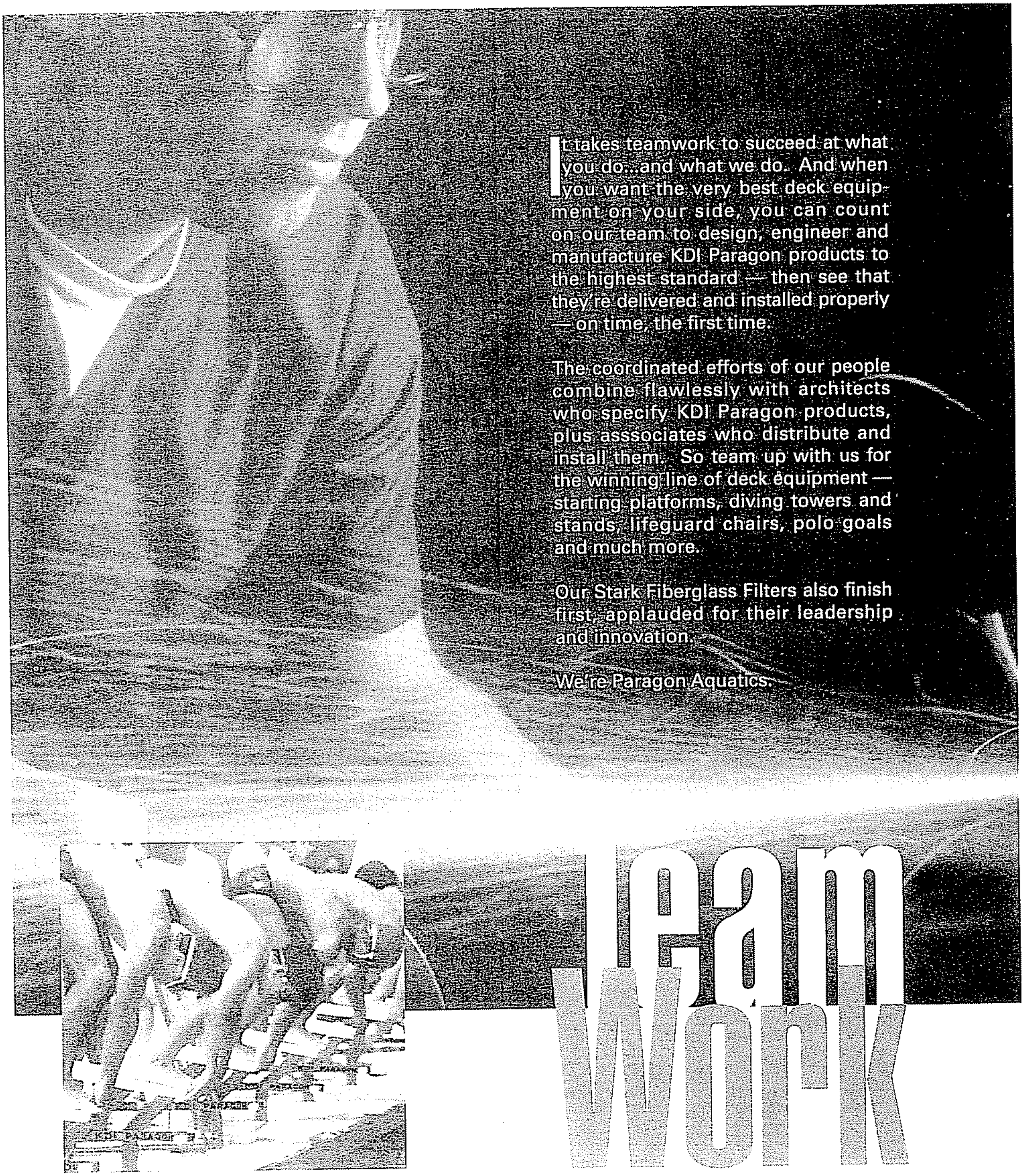

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An invitation...

The most recent lay swim publication I received has got me thinking. Turns out the first three pages of that magazine held advertisements for the new body suits, which supposedly incorporate futuristic fabrics. It seems to me that these advertisements assume that swimmers are either gullible or stupid. I'm not sure which of the two is worse. Why do I propose this? Try these claims on for size.

One company has placed an advertisement which specifically states the materials in their new suits represent "nearly zero friction" and further goes on to claim that their suits "nearly eliminate drag." Excellent indeed...if in fact it works. While this is obviously a material that Newton, Goddard and even Einstein would have marveled at, it is my contention that the old adage, "if it sounds too good to be true...it probably isn't," surely must apply. Imagine for a moment the risk a swimmer might face if after *launching* from the blocks, friction would no longer act to slow his or her velocity toward the opposite wall. Impact would certainly be severe if not lethal. So much for the focus on distance per stroke and such as swimmers simply wouldn't need to worry about strokes. *Launch*, would be an appropriate word in this context, as a frictionless material might allow very easy egress into outer space. Fortunately for the swimmer (not to mention the swim suit company's liabilities in such matters), there is still a little problem called gravity which would act to forestall such orbital launchings. Imagine.

But perhaps just as fantastic to me as the 'frictionless suits', is the claim by the manufacturer that the new suits "deliver all of the benefits of a shave down with none of the hassles." The question I have is, "How do they know this?" Have these companies actually tested this concept? Have they, in fact, isolated the various physiologic, neurologic and psychologic effects of a 'shave down'? Have they further shown that a swimmer wearing a full body suit experiences the pseudo-biologic equivalent of a shave? Or is this simply a cavalier assumption made by someone in their marketing division? Maybe Freud *was* right. Sometimes a cigar is just a cigar... maybe a shave down is nothing more than removing body hair. My question to you is, "Is this what you want your swimmers to believe?"

At the recent USA Aquatic Convention and the ASCA World Clinic, I had the chance to ask a number of retailers and distributers about these fantastic claims. Specifically, I asked who provided the text and captions for their catalogs? The universal answer was, "the suit manufacturers." These retailers stated that they were not responsible for content and in fact they were told that any blame for possible inaccuracies would not be shouldered by them. So, while the retailers admitted that these claims probably couldn't be supported with data, neither did they make any effort to insure that the information they incorporated into their catalogs pertaining to suits, was reasonable or factual. They were simply not to blame and as such, they didn't seem to care.

I next spoke to representatives from several of the major swim suit companies. Were they willing to stand by these claims? "No, not necessarily" was the implied answer. Their responses were either 1) "the marketing group provides the text, not the sales representatives" or 2) "the copy is provided by the fabric manufacturer not the swim suit companies." The buck stops ...where? Unfortunately, representatives from the fabric companies were nowhere to be found. The victims of accidental launchings, maybe?

We are now all too familiar with the advertisements' other claims; vibrating muscles (as a major cause of fatigue), 'muscle compression technology' and 'vortex generators'. Try as I might, I have yet to find anyone of science who is willing to take a stand and even so much as suggest that any of these concepts play a role in limiting or enhancing competitive swim performance.

What concerns me about all of this is that currently, there are no rules in this game and there is an assumption out there that actual proof of a suit's effectiveness isn't necessary. They 1) tell us how much they have spent upon development, then 2) pay top athletes to wear these fantastic suits and 3) later claim that the outcome of the competition was related to who was wearing what. What other proof is needed? This is a page from the same book that the supplement industry indorses as their 'bible'. Sprinkle in a little science, add a pinch of half truth, stir in a whole lot of gullibility and send it to the copy guys. Then get started with the next product before the luster dulls on this one. Fortunately, in the United States at least, we have a system of oversight that requires manufacturers to substantiate their claims, however fantastic they may be. If a company is unable to verify the truth of their advertisements, the manufacturer is likely to be, and should be asked to stop doing so or be charged with "false and deceptive" advertising under the auspices of the Federal Trade Commission.

Of course if these companies could prove their suits provide a definitive advantage, they risk having them classified as equipment rather than costumes and they would, of course, be illegal. Right? Or alternatively, the suits could die a quiet death and the swim community might just be better off for it.

But maybe it doesn't have to go this far. Let's, as advisors to these companies and trustees to the thousands of young swimmers, their mothers and fathers, demand to see the numbers. Let's ask the companies to provide us with empirically derived data, the numbers that support their contentions of new suits with 'nearly zero friction' and suits which eliminate the dreaded 'vibrating muscles'. An invitation is extended here to allow this data to withstand the rigors of science and let it be reviewed by knowledgeable peers. And, if the companies can't (or won't) allow science to confirm these claims, then let's advise our athletes, paraphrasing the words of the great sprinter Alexander Popov, that their own skin, might just be the best skin, to swim in!

This issue of the Journal of Swimming Research is, in my mind, full of surprises. First, I ask you to consider the Report of the Ad-Hoc Committee on the International Center for Aquatic Research. This represents a considerable effort of a number of our colleagues and raises important issues and potential solutions. I invite you to provide further input, either privately to John Leonard or openly to me in the form of "a letter to the editor." A definite 'must read', is the article by Termin and Pendergast. This certainly should challenge doctrine and stimulate debate upon what it takes to train swimmers to swim fast. A second article of particular interest has been authored by Zoeller and colleagues pertaining to the use of blood lactate measures. For something completely different peruse Leclerc et. al, who tell tales of long distances and cold waters. Ever have concerns about shallow waters and racing dives? Read the manuscript contributed by Blitvitch and colleagues from Australia. And finally, Dave Tanner has presented us with another fine edition of "In Print." Use it. Read.

Once again, thanks to all of the associate editors and reviewers, authors, typists and sponsors for allowing/permitting/making it possible for another issue of Journal of Swimming Research to go to press.

JM Stager

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Final Report—ASCA Swimming Science Review Committee

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DATE: 31 May 2000
RE: Committee Report to the Board of Directors

"Coach Driven-Athlete Focused-Administratively Supported": Science in the Service of Swimming

Introduction

This committee was originally charged with reviewing the operations of the International Center for Aquatic Research (ICAR) and bringing recommendations to the ASCA Board regarding "the optimum direction for the operation of ICAR". Additionally, we were charged with recommending "optimum conditions, needs and actions to ensure adequate sports science support within USA Swimming".

Almost as soon as this committee was formed, word of its existence spread throughout the United States and even around the world. The committee had no shortage of suggested direction from both ASCA and WSCA members. Through this immediate, and almost unanimous, feedback both our President and Executive Director agreed to amend our charge (slightly) to, "Recommend optimum conditions, needs and actions to ensure optimum sports science support within USA Swimming, as well as the optimum direction for the operation of the ICAR".

The immediacy of the response from our members, as well as the now successful model in Australia, showed the committee and the ASCA Executive Committee that one of our key problems has been that we have had "the tail wagging the dog". The ICAR should be (and should have been) an offshoot of our Sports Science Program. Our Sports Science Program should not be (or have been) an offshoot of ICAR. Although this may seem like mere semantics, this report should make clear both the significance and importance of this approach.

ICAR has been essentially dormant as a research center for the past eight (8) years. 1992 and 1993 were watershed years for ICAR. By 1992, much of the research produced by the staff was lacking in credibility with both the coaching and scientific communities. Often its research mission was compromised by its "marketing" potential.

Dr. William Huesner, one of the seminal swimming researchers in the United States, was charged with developing a committee of outside sports science people to review the operations of ICAR and make appropriate recommendations. The report of that (very prestigious) committee was legally sealed to "protect USS from potential litigation".

Through the end of Ray Essick's tenure and the early stages of Chuck Wielgus' tenure, ICAR remained in dormancy. This

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year, with almost no fanfare and no input from the coaching community, USA Swimming has began to hire staff and re-open operations at ICAR, without an obvious operational plan, or even a mechanism to avoid the mistake(s) of the past. In order to provide (unsolicited) input from the coaching community and to help prevent the wasted efforts and mistakes of the past, this committee was formed.

In the past two (2) quadrenniums, the United States Olympic Committee (USOC) has been aggressively promoting "resident teams" among its member National Governing Bodys (NGBs). One of the key benefits of the resident team approach is the ability of a USOC Training Center to provide tremendous support for both coaches and athletes. In addition to the obvious room and board, specialists in physiology, biomechanics, psychology, nutrition, sports medicine, physical therapy and massage are all available to resident team athletes.

This holistic, team approach is almost identical to the array of support afforded to NFL and NBA athletes, as well as our top NCAA Division I schools. The services offered by sports science are more valued than the research potential of the sports scientists by most practicing coaches and athletes. This is no less true at the club (grass roots) level, than it is at the elite international and professional levels.

The Eastern European "sports factories" were presumed to be models of this kind of integrative approach to the use of sports science, although now the world knows them to have been both scientifically and athletically corrupted by extensive doping. Australia may now be the best model of a nation that has succeeded in integrating the service potential of the sports sciences in a true collaboration with their coaches. This seems to be true from the elite to the grass-roots levels. In fact, each year there seems to be less of a distinction between the elite and the grass roots in Australia, as it appears they have self-consciously de-centralized both their sports science and their training systems.

As an open, English-speaking society, with a long history of a friendly rivalry with the United States, the Australian model has been relatively open to observation and questioning by American coaches. We have been able to watch from a distance and see their national strategy change as a result of their early failures; and we have witnessed their emergence as the leading nation in the world in men's swimming as a result of their national change of direction.

Their early failures are largely attributed to misguided attempts at centralization to sports academies and institutes, as well as an imbalance within their national sports science committee structure, with physiologists dominating their scientific peers in both number and influence. They attribute their current successes to a deliberate de-centralization, accompanied by the development of significant sports science support networks at the club level throughout Australia. Their code words have become coach driven-athlete focused-administratively supported.

Parallels for the Australian Sports Science model not only exist in professional and collegiate sports, but in private industry, as well. Our committee was privileged to get an insight into the science support system in the 3M Corporation. 3M has three levels of labs to support its sales and engineering staffs, as well as its customer base.

3M's Division Labs work closely with their customers and focus on quality improvement. The typical timeframe for Division labs to see results of their projects is 6-24 months. Inside the Division Labs are Technical Service teams. These teams serve as the two-way bridge between the Division scientists and engineers and the 3M customer.

The Technical Service teams work closely with the customers to define needs, address problems, highlight new products /services/information needed by the customer, while simultaneously acting as the internal voice of the customer to 3M's technical community.

The parallel between 3M's Technical Service team and the proposed Sports Science Support network were too obvious to miss.

The next "level" of labs at 3M are the Group Labs. Interestingly, they work independently from all of their operating divisions and focus on new technologies that are applicable to specific market centers. At the Group Lab level, results of projects are expected within a 2-3 year timeframe.

3M's Corporate Labs are the "Blue Sky" labs that we have all read about in the popular press. These labs are specifically charged with developing groundbreaking new products of technologies within a 3-5 year timeframe.

Looking back at our recent sports science history and outward to what is being done collegiately, professionally, internationally and commercially, gave us the perspective to recommend a focus for USA Swimming's Sports Science efforts.

Bottom-Up Focus

Both the Australian and the 3M models have very similar structures. They are driven by a "bottom-up" focus, with intensive support for the customer (end user/swimmer) and their vendors (sales engineers/coaches). It is this commitment to the base of their operations that drives all other aspects of their operations.

Often, American coaches have been presented with a false choice between a national focus on new research or applying the information that already exists. This is not a choice. It is a straw man. Although we may not be able to implement the entirety of the Sports Science program immediately, we must follow our priorities and build the program from the bottom up.

The focus of a "bottom-up" program is quality improvement. The quality of coaches and coaching; the quality of clubs and management; the metric will be the quality improvement of swimmers, faster times.

This quality improvement goal will be effected through two (2) interventions. The first will be the service (applied science) component, provided through collaborations with local colleges and health care professionals. The second intervention will be the research component, provided by USA Swimming Swim Science Interns.

The goal of the applied science service collaborations is to help coaches access data that will help them make better coaching decisions. Typical decision areas are:

- Physiology
- Biomechanics
- Psychology
- Nutrition
- Sports Medicine
- Physical Therapy
- Massage
- Information Technology
- Hydrodynamics
- Motor Development, Learning and Motor Control
- Biostatistics and Epidemiology
- Quality Control

The research goals of the Swim Science Interns are to develop baseline data and metrics on major clubs that have historically developed homegrown, national swimmers. Methods would include archiving and analyzing workouts and seasonal plans; recording baseline data; administration of testing to both senior and age group athletes; and tracking "elite" senior and age group swimmers.

This data will be used to develop (among other things) both coach and club productivity measures, using large data sets, following industrial engineering, biostatistics, epidemiology and quality control models and protocols, among others.

In addition to the swimming technical data, basic club management studies will be done including structure, finance, governance and continuing education.

Swimming Research

Just as the "club-level" Technical Service Teams were based on the 3M model, so are the two (2) levels of research proposed by this committee.

One of the new missions of the USA Swimming Institute has to be to develop a new generation of swimming researchers in the United States. The "lions" of American Swimming Science are graying, retiring or dying, and few swimming scientists have been trained or inspired to take their places. Fortunately, this ancillary mission of researcher development dovetails neatly with the need and desire to distribute three (3), specific categories of research among interested universities around the country.

No organization does basic science research better than universities. This is even widely acknowledged in the private and non-profit research centers. In addition, this committee proposes that coach-directed research into the use of existing technologies and into the application of the social sciences be specifically directed to university settings through an annual grant Request for Proposals (RfP) mechanism.

Specific issues that have been brought to this committee's attention for university research in the use of existing technologies are velocity measurement and materials testing (suits, etc.). Social science issues that have been brought to this committee's attention were in the areas of contemporary sociology and marketing. Specific coach requests for research in basic sciences have been in the areas of motor development, learning and motor control in the aquatic environment.

The United States Swimming Science Institute (USSSI) would be USA Swimming's version of the 3M Corporate Lab. The demands on the USSSI would be similar to those on the 3M Corporate Lab, groundbreaking research with an expected 3-5 year application timeline.

In addition to the "blue-sky" research, an equally strong applied science section is also needed within the USSSI, focussed on solving specific, coach-directed problems. Examples that have been brought in front of this committee are:

- Which suit is faster?
- Which streamline is faster?
- Altitude training
- Tapering
- How much rest is "*short rest*"?
- What tests/trains VO_2 max?
- Strength training

In order to achieve these dramatic goals for the USSSI, many collaborations will be needed. No single entity can, or should, be expected to "go it alone" and achieve these far reaching goals. Some of the most frequently requested (of this committee) collaborations would involve computer and video technology in the area of stroke mechanics.

"Historical" stroke mechanics, including the archiving of old film and video onto digital media and "comparative" stroke mechanics, including the split-screen digitization of developing swimmers, side-by-side with recognized champions are frequently mentioned, along with "evolutionary" stroke mechanics, where force-lift-drag equations are used to computer model proposed changes in stroke mechanics.

Proposed changes must not only be computer modeled using computational fluid dynamics (CFD), they must be "proofed" in the water using evaporative dye studies.

This could serve an excellent opportunity for "collaboration" between the USSSI and a USA Swimming Corporate Partner (General Motors), as CFD and evaporative dye studies have been refined to the "state-of-the-art" in the automotive industry.

The other area of computer modeling that has been brought to this committee with some regularity is in the development of training models and test sets, areas that would clearly lend themselves to collaborations between the USSSI, university researchers and "coach-hackers" (who have done most of the development to date).

The USSSI can, and should, be a focal point in the development and application of "advanced technologies". Again, an area that lends itself to both formal and informal collaborations with engineers and "coach-tinkerers", these collaborations should be expected to develop, or assist in the development of new products for the swimming marketplace.

Structure of the USSSI

Throughout this paper, we have been referring to the International Center for Aquatic Research (ICAR) as the United States Swimming Science Institute. This "renaming" is both symbolic and purposeful.

ICAR has never been international. Many other nations have their own centers for swimming science, Australia, Japan, Germany, Sweden, Spain and China to name a few. ICAR has also never been "central". Many of the previously mentioned nations have produced a significantly greater volume of peer reviewed, published swimming research. Much of that research has also been more directly applicable by coaching practitioners.

Further, this committee has recommended a "domestic", not international, focus to the entire swimming science system. The Institute is no different. It must have a domestic focus; be driven by domestic coaches; answering domestic questions.

The Institute should also not be "central". The Bottom-Up focus demands that our clubs be central in this process. Funding and focus on the development of the Institute must be secondary (or tertiary) to the development of the grass-roots program.

Once the grass-roots program and the university research grants are in place, the USSSI needs to be redeveloped. It is the recommendation of this committee (and many USA Swimming staff members seeking anonymity) that the USSSI be insulated politically from USA Swimming. We recommend that the USSSI be developed as an independent, nonprofit corporation, with an independent board and budget, much like the United States Sports Insurance Corporation (USSIC).

In fact, if the very successful model of the USSIC were used, political and structural independence would be created, while still remaining joined by USA Swimming driven goals and funding guarantees.

The most important aspect of the entire United States Swimming Science effort depends on the leadership of this effort. The Executive Director of this independent corporation must be responsible for directing the entire swimming science effort, not merely the USSSI.

The Executive Director does not need to be a scientist. The Executive Director must be able to handle multiple priorities by building collaborations, not resorting to power, or office, politics. The Executive Director must be a proven manager of multiple, high-priority, high-budget projects. The Executive Director must have a history of managing "stars": highly skilled, high performance, technical specialists.

At all levels, from the grass roots, club-service, through the university grants, to the USSSI, including all the necessary collaborations, an "open structure" must be maintained. This means that all results from all, ongoing research will be available to all participants, at all levels, all the time. This will require a significant commitment to use of the internet and web pages for projects, but is essential for developing credibility in the system.

Similarly, credibility must also be developed within the scientific community. As projects come to completion, all results must be published and there must be no publication without peer review. In the case of interim result publication on web pages, or internal publications, lack of peer review must be noted.

Second in importance only to the leadership of the USSSI Executive Director is the composition and management of the "Study Section" for the USSSI. The Study Section is a group of volunteer scientists and coaches who meet, in person, twice a year. The first meeting is dedicated to developing the "questions" for the coming year's round of research and grants, prioritizing those questions and developing Requests for Proposals that address those prioritized questions.

During the second meeting, the Study Section sorts through the RfP responses. Based on the prioritized list of questions and the research budget for the year, the Study Section determines the fund allocation for both the basic and applied research.

Ideally, the Study Section should be coordinated by a full time Project Manager. It should be comprised of one (1) researcher in each of the identified swimming science disciplines (Physiology, Biomechanics, Psychology, Nutrition, Sports Medicine, Information Technology, Hydrodynamics, Motor Learning, etc.), two (2) statisticians and one (1) USA Swimming Corporate Partner representative who is familiar with research in their industry. In addition to these twelve (12) members, at least six (6), national level coaches (or, 1/3 of the total Study Section), of both elite and age group swimmers, should be members of the Study Section.

The Project Manager would, in addition to providing staff support to the Study Section, develop and coordinate an input process from all USA Swimming coaches to the coach-members of the study section, as well as an input process from swimming researchers to the researcher-members of the Study Section. Both the Project Manager and the Study Section itself would have to develop an evaluation process for the research outcomes.

Even in-house researchers should submit blind proposals to be evaluated by the Study Section, reviewed by the same process and grouped with outside researchers' proposals.

The legal, staffing and location of the USSSI, although controversial, must not be ignored. For the purposes of this committee's initial recommendations however, only legal and location will be dealt with. The issue of staffing will be reserved for the possible development of an implementation plan, at the direction of the ASCA Board of Directors.

Even more controversial than the possible legal issues at the USSSI is the possibility of re-locating the USSSI. Since before its inception, Colorado Springs has been a controversial site for what is currently the ICAR. In the discussions leading to the development of the ICAR, Counsilman was vehemently opposed to locating the research center at altitude.

Although the flume itself can be controlled for altitude, in every other aspect, from eating and sleeping to blood tests and psychological profiles, the subjects are "sojourners at altitude" (Senay and Robertshaw). Additionally, Colorado Springs is located near what many researchers consider to be the "breakpoint", or threshold, for the altitude response. This means that there would be a great disparity in the responses between individual athletes (from none to full response) and even within a single athlete on separate trips to Colorado Springs. Thus, research data collected at Colorado Springs may not reflect normal physiological, psychological or biomechanical responses and may not provide data that is useful or informative to coaches and swimmers.

More recently, the lack of a large swimming population in the Colorado Springs area has become an issue. Many coaches and researchers believe that the USSSI must be located in, or near, a large and diverse swimming population, enabling it to develop large data sets in its research.

The lack of an intellectually diverse and dynamic research hub in Colorado Springs has also been cited as a source of academic sterility and creeping research sloppiness that plagued ICAR in the past. In order to combat this, locating the USSSI at a major research university, or on the "campus" of a private-sector research center should be considered.

As compelling as the rationale for relocating the USSSI away from Colorado Springs is the rationale for leaving it on the campus of the US Olympic Training Center. In addition to continuous National Team access, the ICAR enjoys both physical and fiscal support that would be difficult to equal elsewhere.

Although we should seriously investigate locating the USSSI to a near sea level, swimming population center, in collaboration with a research university, we must maintain the physical support, fiscal support and athlete support that the ICAR now enjoys.

The issue(s) of intellectual property rights must be decided well in advance. It is the recommendation of this committee that the USSSI follow the examples and protocols commonly used at research universities. These are both time and court tested, as well as conducive to a stimulating intellectual environment. The USSSI must be <u>the</u> incubator for swimming innovation, providing engineering, manufacturing, patent, copyright and marketing assistance—even small project development funding--for product developers, whether they be stroke films, exercise machines or computer programs. In the past, many swimming coaches have developed and openly shared many ideas and products, only to have their ideas "stolen", with no credit acknowledged or royalties paid.

This repeated "theft" of intellectual property has diminished both the willingness to share and the energy to innovate. We must ascertain that both credit and compensation are appropriately dispensed.

Although the swimming market is very small, it is easily feasible that products developed at the USSSI would have "cross-over" value to the larger sports or healthcare marketplaces. Along with the intellectual property rights issues come issues of patent ownership and the (financial) rights of the athletes and coaches who participated in, or contributed to, the development of any potential products.

Implementation

As stated earlier in this report, in order to recommend "optimum conditions…for swimming science support within USA Swimming" and the "optimum direction of the ICAR" this committee developed a *USA Swimming Science Support and Research Network* (Swim Science Network) that is grass-roots focused and supported by the United States Swimming Science Institute (USSSI). The Swim Science Network works simultaneously at three levels, with all three levels being supported by USSSI.

Grass Roots First

The first level to be developed in the Swim Science Network should be the Science Support Network (SSN). The USA Swimming Sport Development Coordinators, in conjunction with local clubs, organize the SSN, supported by the USSSI staff and associate scientists.

Local SSNs will consist of local scientists, researchers and medical professionals who have indicated a willingness to: support local clubs, conduct local research and both attend swimming specific seminars within their discipline and spend weekly "deck time" with a national-level coach in their area, in order to "get up to speed" on swimming specific issues within their field.

The USSSI staff and associates will: serve as a model SSN in order to support the current National and Resident Team Coaches (as defined by the National Team Director); conduct research selected by the National Team Coaches; and conduct the "swimming specific seminars" for the local SSN professionals within their discipline.

The USSSI will be coordinated by the USA Swimming Director of Sports Science. It is important that all of the identified disciplines be represented either by USSSI staff or associates. In the event that there is not a staff position in a particular discipline, the Director of Sports Science must recruit associate scientists, researchers or medical professionals. *[Budget Implications: 9, $5000 annual stipends to non-staff associates. Sub-total: $45,000. (Running Total: $45,000)]*

One area that has been repeatedly identified as a major weakness in the ICAR/USSSI staff/associate structure is statistics. Staff should be hired, or associates developed, in population statistics, biostatistics and epidemiology, sequential statistics, as well as developmental (industrial-type) statistics. This should be one of the first areas addressed as the USSSI builds its staff and associate infrastructure.

Clubs participating in the SSN must commit to a 2:1 matching grant with USA Swimming for professional stipends for the local scientists, researchers and/or medical professionals who participate in the network. *[Budget Implications: 4, $2000 matches/Zone. Sub-total: $32,000. (Running Total: $77,000)]*

USA Swimming must assume the costs of the "swimming specific seminars" for the various disciplines. If possible, these seminars should be coordinated with the annual conventions of those disciplines, in order to reduce the travel expenses to USA Swimming. *[Budget Implications: 12, seminars conducted in conjunction with annual professional meetings. Travel $750 each. Meeting costs $1250 each. Sub-total $24,000. (Running Total $101,000)]*

Swim Science Interns

As soon as the SSN is initiated, the Swim Science Intern program should be implemented. These Field Interns will be assigned the task of monitoring all training aspects (archiving all workouts, recording data, administering USSSI-standardized testing, tracking selected athletes, as well as serving as an assistant to the Head Coach) of selected clubs. Additionally, these interns will collect a limited amount of club management information and data.

The clubs will be selected based on National Junior Team placement, as well as the number and performance of 18 and under men/16 and under women at USA Swimming Nationals.

The Swim Science Interns will "enlist" for a period of 15 months. The first three months (June through August) will consist of training by the USSSI staff and associates, the USA Swimming staff and the staff of the ASCA. September 1 through August 31, the Swim Science Interns will serve in their internship capacity with the selected club. A club and an intern shall be selected only once for this program.

The interns will be responsible for disseminating the collected data on a designated web site that will be available exclusively to the USA Swimming coaching community. Additionally, the interns will meet as a group at the US Open and both USA Swimming National Championships, to discuss their findings under the direction of the USA Swimming, the USSSI and the ASCA staffs.

These findings, both technical and managerial, will be disseminated nationally by the USA Swimming Sport Development Coordinators and will be available to all USA Swimming coaches at the designated web site.

Participant clubs must commit to a 2:1 matching grant with USA Swimming, to cover the intern's salary for the year. Travel costs during the year will be covered by the selected club. All expenses during the three-month training period will be the responsibility of USA Swimming. The Programs and Services Director in the Sport Development Division will coordinate the Swim Science Intern program. *[Budget Implications: 2, $7500 matches/Zone. Sub-total $60,000. 8 interns' summer training expenses, $1500 each. Sub-total $12,000. 8 interns' travel, $500 each. Sub-total $4000. (Running Total $177,000)]*

Research

In addition to the coach-selected research done by the local SSNs and the USSSI staff and associates, annual, grant-based, cutting-edge, competitively selected research must be a staple of the USA Swimming Science Support and Research Network.

A group of coaches and scientists must develop an annual set of research priorities and develop Requests for Proposals (RfPs) to solicit responses to those priorities from reputable researchers throughout the country.

This group must spend the year preceding their meeting scanning areas that merit further investigation, from the mundane to the pragmatic to the "pie in the sky". They should be reviewing research in other disciplines for its potential applicability to swimming.

Once the annual research priorities and RfPs have been developed and distributed to universities, private sector research institutes and the USSSI staff and associates, a Study Section will be developed to review the responses and select the projects to be funded within that year's budget. This competitively based research must form the bulk of each year's research budget. *[Budget Implications: 6, $25,000 grants. Sub-total $150,000. (Running Total $327,000)]*

Diversity of disciplines is critical both in the committee that establishes the annual priorities and in the Study Section, because it is at the edges of paradigms and the intersections of disciplines where breakthroughs and maximum returns are usually found. No more than one scientist, researcher and medical professional in each discipline should serve on the Research Priorities Committee and the Study Section. Conflicts of interests in both of these groups must be scrupulously avoided.

The Director of Sports Science shall provide staff support to both the Research Priorities Committee and the Study Section. Both the Committee on Research Priorities and the Study Section will require multi-day, annual meetings. *[Budget Implications: Travel for 18 committee members, $500 each. Sub-total $9,000 each group. (Running Total $345,000)]*

Once the research has been completed, peer reviewed and published, the USA Swimming Sport Development Coordinators must "translate" this material into language, formats and tools useful to all levels of the USA Swimming community.

Web-based Information Delivery System

It is also essential that the web information delivery system be developed at the front end of this program. For the web to serve as an effective delivery mechanism of the information developed at all levels of this network, three (3) areas of web expertise will be required:

- Web based training and presentation skills, including web ergonomics and web psychology;
- Physical and electronic research librarian skills, including a legal understanding of copyrights; and
- Internet and Intranet development skills, including experience in SGML and XML.

Not only must the individual(s) have the above-mentioned skills; they must have demonstrated those skills in a large-scale web information environment. The combination of these skill and experience sets would require the hiring of one, very experienced (expensive) individual, or a group of individuals who possess all the requisite skills and experience (also expensive).

For this reason, corporations about the same size as USA Swimming often find it more cost-effective to outsource their web development and maintenance. What is difficult is simultaneously outsourcing the swimming background necessary to put the research content and discussion groups in perspective.

The USSSI web development person/group must be able to take the information developed by the local research projects, the Sports Science Interns and the Grant-based research and convert it into effective media that are useful to both coaches and "new-to-swimming" researchers.

The individual/group must be able to effectively moderate a *closed* internet forum; maintain both a high level and technical focus in the forum, while still encouraging controversial and cutting-edge technical content; glean information from the forum and pass it on to the Committee on Research priorities; and contact researchers and coaches to solicit additional, or clarifying, information for the forum. *[Budget Implications: $35,000 at 10% of total budget. (Running Total: $380,000)]*

Evaluations and Accountability

A "360°" evaluation process should be used for the participating clubs, scientists and USA Swimming staff members participating in the SSN.

Participating coaches will evaluate both the scientific support received from their local network, as well as the staff support received from USA Swimming. Participating scientists will evaluate both the coaches and the USA Swimming staff. The USA Swimming Sport Development Coordinators will evaluate both the participating coach and local scientist/medical professional.

A similar "360°" degree evaluation process will be used for the Swimming Science Interns.

The interns will evaluate the selected club based on access to information and support of the project, and their USA Swimming Sport Development Coordinator based on the coordinator's ability to facilitate their project. The host coach will evaluate the intern based on skills as an assistant coach and the intern's ability to unobtrusively complete the research, and the USA Swimming Sport Development Coordinator's ability to assist both the host coach and intern during the internship year. The USA Swimming Sport Development Coordinator will evaluate both the host club/coach on access to information provided to the intern, as well as the intern based on follow-through and presentation/analysis of the intern's research.

For the grant-based research, evaluation is as important as the research itself. The Study Section will evaluate the previous year's research, immediately prior to awarding the following year's grants. If expertise, outside of that available in the Study Section, is needed to evaluate a given project, the Chair of the Study Section should seek that expertise.

The final evaluation should include a statement on whether the Study Section would recommend future funding for:

A. the researcher, based on the quality of that study, and
B. the subject matter, based on its potential applicability to swimming.

The USSSI legal counsel, prior to publication, should approve all final evaluations.

Statement of Ethics

Research done at all levels of USA Swimming Science, including the local support networks, the swimming science interns, grant-based research, and the USSSI, must be structured and preformed for submission to and publication by peer-reviewed research journals.

This includes, but is not limited to, research driven by locally determined needs; research conducted as a part of the swimming science internship; research driven by the Committee on Research priorities; research requested by the National Team coaches; and research preformed on the behalf of sponsors or other for-profit entities.

Specifically in the instance of research preformed under contract with an outside party, "non-disclosure" agreements shall be negotiated—in advance—by the Assistant Executive Director for Sports Development. No researcher(s) shall be a party to the negotiations.

The purpose of the negotiations is to:

A. Allow the funder of the research the opportunity to get a product to market, while maintaining competitive advantage, and
B. Allow the swimming-related research to be submitted for publication in the most expeditious manner possible.

The Assistant Executive Director for Sport Development shall be bound by the duty to get swimming information back to the swimming community in the fastest, most accurate and most complete manner possible.

Conclusions

Although the report of the committee specified an independent USSSI, the implementation plan begins as a part of the current USA Swimming structure. This should in no way be considered a "backing down" or "watering down" of the committee's intentions, but as a practical means by which to get the complete program up and running.

Once the program is fully operational, the issues of an independent corporate structure, possible location changes, etc. must be addressed, however our commitment of service to athletes through coaches must not be delayed while political issues are addressed.

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Training using the stroke frequency-velocity relationship to combine biomechanical and metabolic paradigms

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Abstract

Current conventional swim training tends to focus on long over-distance swimming, often in combination with dry-land strength training and a season ending taper. This study evaluated the effectiveness of a novel training regime incorporating high-velocity swimming exclusively, without dry-land training or taper. Twenty-two Division I swimmers who trained on the high-velocity program were followed over their four competitive seasons and their performances in the 100 yard and 200 yard freestyle were tracked and shown to improve 8-10% over this time. The improved performance of the high-velocity group was coincident with a 20% reduction in the energy cost of swimming which was associated with a shift of the stroke frequency-velocity relationship toward one in which the body traveled greater distances per stroke (16%), with an increased maximal stroke rate (8%). Maximal aerobic power (48%), anaerobic power (16%) and anaerobic capacity (35%) increased in these swimmers during the four years studied. Their swim velocities increased 31% for speeds that could be sustained aerobically and 27% for maximal speeds. All of these changes are substantially greater than what is reported in the literature for conventional swim training programs. It is concluded that a swimming program using high-velocity training and primarily based on the stroke rate-velocity relationship, can improve a collegiate swimmer's biomechanics and metabolism ultimately leading to enhanced swim performances without dry-land training, over-distance training or a taper.

Key words: oxygen consumption, lactic acid, swimming performance, stroke frequency biomechanical and metabolic swim training

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Introduction

Success in competitive swimming is based upon the time required by an athlete to cover various distances in the water using one or a combination of strokes. If the starts and turns are ignored, then the time required to cover a given distance can be expressed as a velocity. The ability to achieve and maintain a velocity over the distance of a race is related to biomechanical and metabolic factors. Among the important biomechanical factors are stroke frequency (arm cycles/min) and the distance that the body travels per stroke (m/stroke). Previous studies have shown that there is a characteristic relationship between stroke rate and swim velocity (5,10,11). These investigators have also shown that faster swimmers swim with a greater distance per stroke at both slow and fast speeds, have a greater ability to shorten their stroke, and have a higher maximal stroke rate. Craig and colleagues have shown that elite swimmers swim shorter distances per stroke and slower stroke rates during all competitive events than they theoretically could (based on their individual stroke frequency-velocity relationship) (11). Hypothetically then, increasing either the distance per stroke or stroke rate or both, would improve swim performance.

The metabolic factors important in swim performance are a combination of aerobic (VO_2), and anaerobic (anaerobic glycolysis leading to lactic acid build-up and high-energy phosphate metabolism) (4). Although the rate of energy required is determined by body drag and net mechanical and propelling efficiency while swimming (12,28), it can be expressed as the sum of VO_2 and the rates of anaerobic glycolysis and high energy phosphate use. The relative contribution of these pathways is dependent upon the velocity and distance of the competitive event (4). The ability to achieve and maintain a velocity is dependent upon the rate of energy cost of swimming at that velocity, and developing and supporting the external power with muscular (24) and metabolic (3,4) power. A decrease in the energy cost of swimming by improved biomechanics and/or an increase in metabolic power through effective training should act to improve competitive swim performance.

Previous studies have described the energy cost of swimming and the metabolic pathways that provide energy in recreational and competitive swimmers (3,4,12,30,31) and have evaluated these factors before and after training (4,30,31). Relationships between the energy cost of swimming, distance per stroke, stroke rate and the velocity of swimming have been reported (30). It has not been demonstrated if, or by how much, the stroke frequency-velocity relationship or the energy cost-velocity relationship can be shifted in an individual swimmer with training. It has also not been demonstrated which type of training is optimal in this regard.

Arguably, over-distance swimming ranging from 60 - 80,000 yards or meters per week, is the conventional swim training since the late 1960s, 1970s and 1980s. It might be suggested that due to the long-distance, the speed of training may not be great enough to cause the adaptation(s) needed to swim at the competitive velocities. This over-distance training has the potential to result in chronic fatigue in many swimmers. Chronic fatigue may lead to a compromise in the immune system, mental stress, fatigue and caloric deficit (14,17,18,29).

A "taper" is often used with long-distance training to allow swimmers to recover prior to a championship event. (14,21). The taper improves performance about 3% (14,20,21); however, at least one report indicates collegiate swimmers training with this method improve less than 1% per year (9). Several questions can be raised about the effectiveness of long-distance programs. The chronic fatigue accompanying this type of training may compromise the swimmer's ability to perform during training as well as during meets. Recently, it has been recognized that most competitive swims are at high stroke rates and at metabolic powers which emphasize anaerobic metabolism (4). A limited evaluation of high-velocity (intensity) training has been shown to improve biomechanics and metabolism in competitive events (16).

The purpose of this study was to determine the effects of a novel training regime using higher-velocities and shorter training distances, on the stroke frequency-velocity relationship, energy cost of swimming, and metabolic power and capacity. Further, the outcome of this high-velocity training, i.e., the improvement in competitive swim performance, will be compared to results previously reported for standard conventional swim training.

Methods

Subjects: The subjects for this study were Division I University male swimmers. The high-velocity group (comprised of two groups of freshman recruits) were tested every September, December and March during their four-year careers. Twenty-two men who were 19.0 ± 0.2 years of age, 181 ± 1.3 cm in height, 75.02 ± 3.2 Kg in body weight, and 8.1 ± 2.1% body fat, participated.

The pre-college training of the swimmers ranged from 60,000 to 80,000 yards per week. In most cases, pre-college training involved both dry-land exercise and weight training. The results of the freestyle swimmers whose primary events were the 100-yard and 200-yard swims are presented. There were too few subjects for analysis of other strokes and distances. The initial performance times for the 100-yard and 200-yard freestyle were 48.66 ± 0.70 sec and 1:50.17 ± 2.72 sec respectively.

Biomechanical Parameters: The stroke frequency-velocity relationship, as shown by Craig, was determined for each swimmer. The subjects completed a series of swims where they pushed off the sidewall of the pool and swam one width of the pool (22 meters) at a constant stroke rate and velocity. The swimmer started at his minimal stroke rate and tried to achieve the greatest distance of body travel per stroke. With each subsequent swim, the stroke rate was increased while trying to maintain the maximal distance per stroke, until the swimmer felt he had achieved his maximal speed. Thereafter, the subject was encouraged to increase his stroke rate and not concentrate on his distance per stroke. Repeat swims with higher stroke rates were completed until there was no further increase in velocity with increased stroke rate, thus defining maximal velocity. The time and distance (about 10 meters) to swim a predetermined number of strokes was measured during each swim. From these data, the stroke rate, distance per stroke and mean velocity were calculated (10,11). In the first month of the first year, each swimmer was tested on several occasions to insure that the maximal velocity was determined for all stroke rates. The maximal value of velocity for each stroke rate was used to plot the curve used for training. The "swim meter," described by Craig (10,11), was also used in most swims to determine changes in instantaneous velocity during each swim. The data for changes in instantaneous velocity observed during testing were used by the coach to fine tune the swimmer's technique specifically by emphasizing the parts of the stroke that caused acceleration and eliminating aspects of the stroke that resulted in deceleration.

Metabolic Parameters: Two series of metabolic experiments were conducted on each swimmer. The first series was conducted in an annular (donut-shaped) pool, 58.6m in circumference and 2.5m wide and deep. The swimmer followed a monitoring platform that was driven at a pace set by a water flowmeter (water speed). The swims started at 0.9 m/sec for three minutes and then, the velocity was increased 0.1 m/sec every two minutes until the swimmers could no longer maintain the speed. Each swim lasted between 8 and 16 min. The subject wore a nose clip and mouthpiece. Expired ventilation was collected in Douglas bags on the monitoring platform during the second minute of each velocity. The volume of the gas was measured with a dry gas meter; the fractions of oxygen and carbon dioxide were determined by a medical gas analyzer (Perkin-Elmer 1100). Oxygen consumption and carbon dioxide production were calculated by standard equations. All equipment was calibrated prior to each experiment. These data represented the energy cost of swimming for aerobic speeds. The (VO_2) vs. velocity relationship was plotted, and the max VO_2 (plateau of VO_2-velocity) and energy cost of swimming (VO_2/velocity) were determined.

To determine the energy cost of swimming at high speeds, and the anaerobic power and capacity, the experiments were conducted in the competition pool, configured for 25-yard swims. The anaerobic power requirement is the difference between the rate of total energy requirement and that supplied by oxidative metabolism. When the rate of the energy cost of swimming is higher than the aerobic maximal, the swimmer will stop or slow down. To determine these parameters, the swimmers were divided into heats of four by their competitive times, in order to foster competition. Swimmers completed a 100-yard swim, waited one hour and then, swam a 200-yard distance. On a separate day, two days later, the swimmers swam a 50-yard competition, waited an hour and then, swam a 400-yard distance. Immediately after each swim the swimmers reported to a heated measurement station and were covered with robes. At 7, 8, and 9 min after the swim, blood samples were drawn from an anti cubital vein. The blood samples were spun in a centrifuge and lactic acid was determined by enzymatic techniques. Based on a previous study, the energetic contribution of high-energy phosphates was considered negligible (4), and the rate of lactate accumulation in the blood was calculated from the swim time and lactate concentration. Assuming this value was the peak lactic acid in the blood and that there was uniform dilution of lactic acid in the fast-water compartments of the body, the rate of accumulation of lactate was converted to an oxygen equivalent (3 ml O2/mM/kg), based on the swimming data of di Prampero (4,12). The oxygen equivalent of the lactate data for the high velocity swims were added to the VO_2 max and plotted with the VO_2-velocity data that was determined during the aerobic swims. This calculation represented the rate of energy cost of swimming (E_T) across all velocities, including competitive velocities. The maximal anaerobic capacity was assumed to be the highest value of peak lactic acid concentration after the 50, 100, 200 and 400-yard swims.

Swimming Performance: Performance data were evaluated based on times recorded from an invitational meet in December of each year, and in the Conference meet at the end of each of the four seasons. The times from the electronic timers used in the meets represented the performance data for all competitive distances.

Training paradigms: The high-velocity program used in this study was based on the biomechanical and metabolic data collected in the pre- and mid-season of each year, for each individual swimmer. The training program lasted 26 weeks during the competitive collegiate swimming and academic year. Although most swimmers trained in the summer, there was no specific training schedule given to them. The swimmers in the high-velocity group did not do dry-land training (27) or strength training (16,25). The high-velocity training was based on the stroke frequency-velocity relationship, which was determined at the beginning and mid-season of each of the four years, and a 10% increase each year of the velocities for all stroke frequencies was calculated ("shifting the curve"). During all four phases of training in the high-velocity group, each swimmer was required to swim at a specific velocity, at a given stroke frequency, that was his maximal distance per stroke for each stroke rate, i.e., swim "on the curve." During all training sessions of the high-velocity group, the coach spot checked each swimmer's swimming velocity and stroke rate using a stroke watch (Neilsen-Kellerman). He then gave verbal feedback during the rest intervals. Each training session was preceded by a warm-up of 20-30min. During the warm-up the velocity was progressively increased from an average of 1.3 m/sec to the training velocity to be used in that training phase. A 20-30min cool-down, where velocity was decreased progressively, followed each session.

The general principal of high-velocity training was to shift each swimmer's observed curve to a new theoretical curve and teach the swimmer to achieve the distance per stroke necessary to achieve the desired new velocity ("dialed in"). This shift was accomplished by first improving the swimmer's biomechanics through verbal feedback based on the observed velocity and stroke frequency. Initially (Phase I or Biomechanical Phase), this was achieved at low speeds where the swimmer could concentrate on trying new biomechanical patterns of stroking (without metabolic stress). When the swimmer could achieve the desired velocity with the desired stroke rate for two successive sessions, the stroke rate and velocity were increased, while the swimmer maintained the distance per stroke ("swimming on the curve"). This training phase also served to stress the musculature, as it required high force generation to maximize the distance per stroke. This phase of the training lasted approximately 2-3 weeks. The average velocities during this phase were 1.32 m/sec initially and were increased to 1.56 m/sec over 2-3 weeks.

The swimmer then moved to Phase II when it was demonstrated that he could swim at the desired velocities using set stroke frequencies. If a swimmer could not achieve the shift in two weeks, his new curve was adjusted to the maximal distance per stroke that he achieved in Phase I. In general, learning of the biomechanical patterns involved more rolling and stretching with the stroke, by emphasizing the entry and early pull, and minimizing the late push past the shoulder. The swimmer was encouraged to "get on top of the water" and minimize his leg kick.

The second phase of the training program (Phase II, aerobic metabolic phase) was started when the swimmer could swim on his curve up to his aerobic maximal. Phase II of the training was designed to improve maximal aerobic power and lactic acid clearance. The training involved swimming on the curve at speeds that the swimmer could only sustain continuously for 10 minutes (115-129% of $\dot{V}O_2$ max). During the next 10 minutes, the swimmer swam continuously at 60% of his $\dot{V}O_2$ max to optimize lactic acid clearance. This cycle was repeated three times over a one-hour training period. During the 6 to 7 weeks of this cycle, as the subject's metabolic power increased, the average velocity was increased from 1.61 m/sec to 1.81 m/sec.

Phase III (anaerobic metabolic phase) was designed to increase stroke frequency to the maximal velocity, maintain or improve $\dot{V}O_2$ max, and add training of the anaerobic metabolic systems. During this 15-16 week phase, the swimmers swam at progressively higher stroke frequencies and velocities, while swimming on their curves. The stroke frequency was increased when the swimmer could achieve an entire session at the prescribed stroke frequencies and velocity, for two sessions in a row. At the beginning of this phase, a series of 16 repeated 25-yard swims with 15sec rest, followed by 1.5min rest, were continued over a one-hour practice session. After the swimmers were able to swim the entire hour on their curve for two sessions in a row, the rest intervals were shortened to 10sec. After one hour of 25-yard swims on the curve was achieved, the swimming distance was increased to 50 yards with a rest interval of 30sec, for a series of 16 repeated swims. As the swimmer improved, the rest interval was progressively decreased to 20sec. Although the swimming distances were short, the rest intervals were short as well. Thus, the aerobic and anaerobic systems were employed over the one-hour practice. Due to the progressive increase in both stroke rate and velocity during the training, the swimmers did not fatigue. However, if a swimmer could not maintain both the stroke rate and velocity during a given session, their stroke rate and velocity were reduced to the preceding level until they recovered. The swimmers progressed to the highest stroke frequencies and velocities that they could achieve during Phase III. This was the stroke rate and velocity that they swam during competition.

A fourth phase of the program was incorporated 21 days prior to their final meets. This phase included ½ hour of 25-yard interval swims with 10sec rest, at progressively increasing stroke rates and velocities. No taper (in the conventional sense) was included in this program. The swimmers trained up to three days prior to conference and national meets.

The training in all four phases was conducted in cycles of two high-velocity days that were followed by two recovery days. The high-velocity days followed the schedule described above. The two recovery days involved short (less than 15 sec) swims with 2-3 minute rest periods. It was assumed that this strategy used primarily high-energy phosphates and did not stress glycogen stores (4). Also included, were low velocity short distance warm-up swims. The recovery days were used to emphasize swimming technique (biomechanics) as well as techniques for starts and turns, by using the swim meter. The two high-velocity days maximized stress and the two recovery days allowed complete recovery, thereby, allowing the swimmers to do quality workouts each high-velocity day without incurring chronic fatigue. The two high-velocity and two recovery day schedule was designed to reduce muscle glycogen during training days and to insure complete recovery of glycogen stores during the rest days (6,7).

Statistical Analysis: Mean and standard deviation data were calculated for all variables. The data from the two groups of swimmers in the high-velocity group were combined for analysis. The data from the high-velocity group were compared as a function of year for each measured parameter by Analysis of Variance for Repeated Measures (ANOVA-RM). To simplify the graphs, only the mean data are shown for the high-velocity group. The variation between swimmers did not influence the ANOVRP as each subject served as their own control.

Results

Subjects: All of the swimmers came from high school or club programs that were using long-distance training programs. As such, the swimmers had to become accustomed to the shortness and intensity of the new program. By the second year the swimmers were, entrenched in, and enjoyed the program. The stroke frequency, velocity, distance, rest intervals and intensity of swimming changed progressively in the high-velocity group and eliminated boredom with the training. There were no significant changes in height, body weight, or body fat over their four years of participation.

Biomechanical Parameters: The stroke frequency-velocity data collected at the end of each season during the four years of training, are shown in Figure 1. Judged qualitatively, training did not affect the shape of the stroke frequency-velocity relationship. The velocities at all stroke frequencies increased significantly from the first to the fourth year, representing a 26% increase. This increase was due to increases in the maximal distance per stroke (16%) and maximal stroke frequency (8%). The range of coefficients of variation of velocity over the range of stroke frequencies tested was 12% to 21%. The shifts in the stroke frequency-velocity relationship within a specific year were about 50% from pre- to mid-season and 50% from mid- to end-season.

Metabolic Parameters: The data for aerobic and anaerobic metabolism at the end-season for the four years of training are shown in Figure 2. These data show that the energy cost of swimming (VO_2/velocity, expressed as oxygen equivalents) decreased significantly over the range of aerobic and competitive velocities. Judged qualitatively, the shape of the curves was similar. The changes in the rate of energy cost were 30% at 1.2 m/sec and 56% at 1.6 m/sec; the latter being the highest velocity observed in year 1.

The maximal speed that could be sustained aerobically (31%) and the maximal speed (27%) increased over the four years (Fig. 2). The maximal aerobic power increased from 3.28 ± 0.12 to 3.93 ± 0.21 to 4.32 ± 0.542 to 4.64 ± 0.57 to

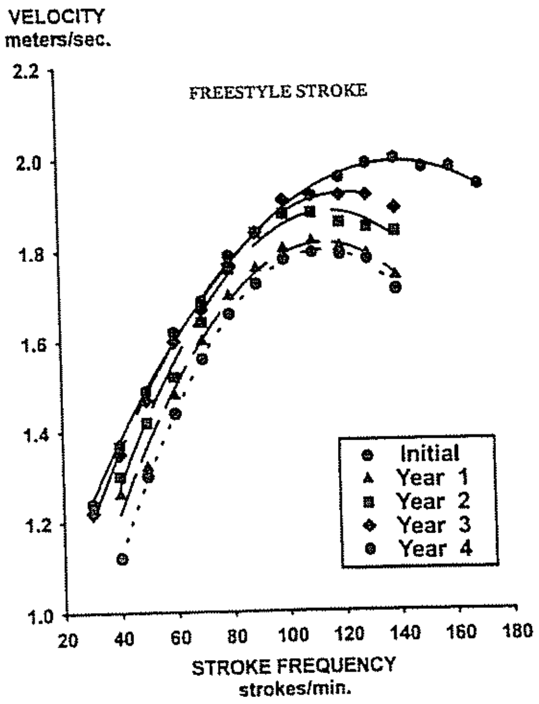

Figure 1. The stroke rate-velocity curve is plotted for the pre-test in year one (initial) and the end-season test for years 1, 2, 3, and 4. Velocity is plotted as a function of stroke frequency. The data are average values for all freestyle swimmers. The data for years 2, 3, and 4 were significantly greater than for year 1 (ANOVA-RM, $p < 0.05$).

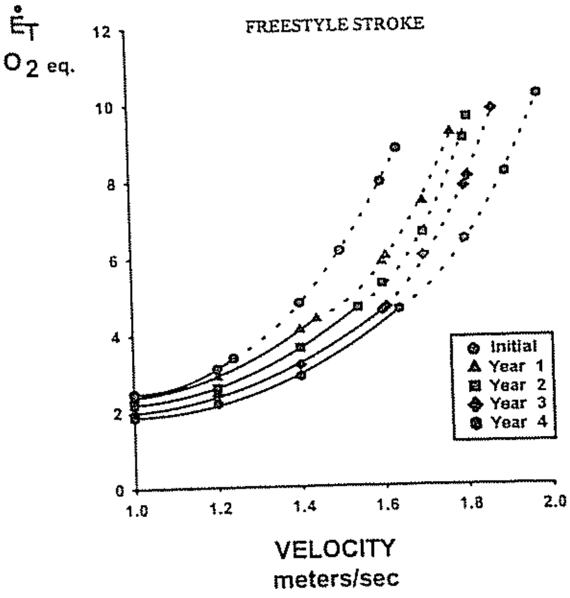

Figure 2. The energy cost of swimming, expressed as oxygen equivalents (E_T), is plotted as a function of swimming velocity. The data are mean values for the pre-test in year 1 (initial) and end-season tests for years 1, 2, 3, and 4. The solid lines are values measured directly, with the final point representing VO_2 max. The dashed line was estimated from values of lactic acid (12). The values for energy cost at all speeds were significantly less for end-season tests at years 1, 2, 3, and 4 than initial test (ANOVA-RM, $p < 0.05$). The values for VO_2 max, maximal velocity and maximal energy output were significantly greater for the end-season tests at years 1, 2, 3, and 4 than initially (ANOVA-RM. $p < 0.05$).

4.86 ± 0.63 l/min over the four years of training (Fig. 2, page 13). These increases represent a 20%, 9%, 8% and 5% increase in VO_2 max for years 1 through 4, respectively, or a 48% total increase.

The maximal post-swim peak lactic acid concentrations were 8.71 ± 0.59, 11.06 ± 0.83, 11.29 ± 0.71, 11.97 ± 1.29, and 11.59 ± 0.88 mM for year 1 (initial), end-season years 1,2,3 and 4, respectively. There was a significant increase in peak lactic acid in the first year (27%). However, the value did not change significantly in years 2, 3 or 4. These peak lactic acids represent anaerobic capacities 1.93, 2.48, 2.54, 2.69, and 2.61 l O_2 equivalents, resulting in a 35% total increase in anaerobic capacity over the four years of training. The maximal total (aerobic + anaerobic) power increased from 8.95 to 9.36 to 9.77 to 10.0 to 10.36 l/min O_2 equivalents over the four years of training. This represented a 16% increase in total power while swimming.

Swimming Performance: The 100 and 200-yard events include both the sprint and middle distance swimmers on the team. The percentage improvements for the 100-yard event were 2, 4, 2, and 2% in years 1-4 respectively, or 10% total. The percentage improvements for the 200-yard event were 1.9, 3.1, 2, and 1.3% in years 1-4 respectively, or 8.3% total. These 8-10% improvements can be compared to a 1-3% or less improvement in 100- and 200- yard events previously reported for Division I collegiate swimmers training with traditional long-distance programs (9).

During the competitive events, the coach of the high-velocity group measured each swimmer's stroke rate and velocity to make sure that the swimmers were swimming on their curves, thereby, insuring optimal performance.

Improvements in swimming performances for distances other than the 100-yard and 200-yard freestyle, or for other strokes where only 2 to 4 swimmers competed, had improvements similar to the 100-yard and 200-yard freestyle for both the high-velocity and long-distance groups. Over the four years, improvements in the 50 yard, 500 yard and 1650 yard freestyle events were 4.59%, 4.42% and 4.89% respectively. Improvements over the four years in the backstroke, breaststroke and butterfly averaged for all distances, were 5.8%, 4.6% and 6.3% respectively.

Discussion

The present study demonstrated that Division I collegiate level swimmers using the high-velocity program described in this study, improved their stroke mechanics and metabolism sufficiently to improve performance by 8% to 10%, for the 100- and 200-yard freestyle, respectively. The improved performance due to the high-velocity training was greater than the 1-3% improvements observed for the more conventional long-distance programs.

The unique aspects of this program are that the swimmers train using the stroke frequency-velocity curve. First, they train at slow speeds to improve distance per stroke. Second, they train at the highest velocity that the maximal distance per stroke can be maintained (maximal aerobic power, anaerobic capacity, stroke mechanics and muscular strength). Third, they train at progressively higher velocities and stroke rates up to maximal (maintenance of aerobic power, stroke rates, anaerobic power, maximal stroke frequencies and velocity). The swimmers described here did not participate in strength training. For the past 30 years, it has been recommended that over-distance training be used to increase the swimmer's aerobic base (11). However, nearly ten years ago, it was suggested that training should emphasize improving biomechanics (11). This type of training involves training with slow stroke frequencies, thus achieving a longer distance per stroke, and then, swimming at progressively faster velocities, and thus short intervals (swimming on the curve) (10,11). It has previously been suggested that optimal swim training should improve biomechanical as well as metabolic weaknesses (28). While swimmers comply with prescribed training distances, rest intervals and even stroke frequencies, they are not able to judge velocity or intensity of swimming very well (26).

Physical characteristics: The swimmers in this study were of similar body size and composition as reported by other studies and these parameters did not change significantly during the four years of training. Thus, improvements observed here are not thought to be due to changes due to growth or maturity.

Biomechanical Parameters: It has previously been reported that elite swimmers have stroke frequency-velocity curves that are shifted up and to the right, greater distances per stroke, and higher stroke rates and velocities compared to less competitive swimmers (5,10,11). The stroke frequency-velocity relationship, when shifted up and to the right, has been shown to be associated with a reduced energy cost of swimming (30). High performance is related to higher stroke rates, greater distance per stroke and the ability to sustain these throughout the race (5,10,11). For most elite swimmers, the shape of the stroke frequency-velocity curves for a specific stroke are similar (10,11). Thereby, improving performance would necessitate a shift in the curve up and to the right. The data from the present study demonstrate that it is possible to shift the stroke frequency-velocity curve by as much as 10% per year, or 40% over four years. Although the data could not be analyzed statistically due to the small number of swimmers, similar improvements were observed in the other competitive strokes and distances. A significant shift in the stroke frequency-velocity curve for competitive velocities would not be expected in swimmers trained with long-distance. This later hypothesis needs to be tested on a population of swimmers engaged in a contemporary over-distance-based program.

Metabolic Parameters: Maximal aerobic power: The present program used three 10min swims at 115-125% of maximal aerobic power. During these swims, lactic acid built up at a rate of 1 to 1.5 mM/min, resulting in maximal lactates being reached after 10min. Ten minutes of slow swimming (60% VO_2 max) was allowed between bouts. This has been shown to be sufficient to clear lactate from the blood (1,12,31). Maximal aerobic power during swimming in low-level swimmers is quite low (3.0-3.5 l/min) (4,8,12,19). The first year VO_2 max values (3.5-4.0 l/min) in this study and other studies (4,16) on higher-level swimmers were similar to values previously reported for less competitive swimmers (12,19). Over-distance training has been reported to result in 4-11% improvement in VO_2 max in one season (19,22,31). However, in the present study, VO_2 max improved 20% in the first year and 40% overall. Other studies have shown that increasing training distance from 4,266 to 8,970 m/day did not significantly affect performance or metabolic power (13,17), and that over-distance training for 5 months does not significantly increase VO_2 max (23). Increasing training distance for 10 days (8,970 m/day) did not increase performance, aerobic capacity, or muscle citrate synthase; however, muscle glycogen was lower than when training 4,266 m/day (6). It may be that low intensity swimming does not provide a sufficient stimulus, or rather, the appropriate stimulus, to improve VO_2 max and that higher exercise intensities, as used in this program and that of a previous study (16), are needed to improve VO_2 max. These data are supported by a study demonstrating that improvements in performance are significantly correlated with mean swimming velocity (intensity), but not training distance or frequency (22).

Swimming performance has been related to the peak lactic acid in blood (1). The data from the present study indicate that the rate of the anaerobic contribution (power) to swimming performance was increased 16% by high-velocity training over the four years of training. The maximal peak lactate increased 35% over the 4 years of training. Previous studies have shown that 8 weeks of high-velocity training increased lactate by 20% over moderate intensity training (15).

High-velocity interval swimming with rest intervals of 30sec resulted in lower lactate levels than swims with 10sec rest intervals for distances of 50 to 100 m. The high velocity training in the present study used 25-yard swims, starting with 30sec rest and decreasing to 10sec rests, thereby, maximizing swimming velocity and oxygen consumption while delaying the limitation imposed by muscle or blood acidosis. Furthermore, the magnitude of the increase in anaerobic power was greater than the increase in anaerobic capacity (as assessed by lactic acid concentration), suggesting that there was increased buffering of lactate by the tissues. Presumably, this happens through increased lactate uptake by the slow twitch fibers within the muscle while fast twitch fibers are producing it.

Summary

The present study examined the competitive swim performance of swimmers trained on a high-velocity and short-distance program without strength training or a traditional taper. A major factor in the swimmers' training was the ability to use the stroke-frequency and velocity relationship to progressively increase the velocity (intensity) of swim training.

The performance improvements from the stroke-based and high-velocity training program are supported by the improvements in the stroke frequency-velocity and total energy-velocity data. The distance per stroke at all stroke frequencies was increased, which led to a decreased energy cost of swimming at all velocities. In addition, there were significant increases in maximal aerobic power, and anaerobic power and capacity, leading to the ability to achieve and maintain higher velocities. Although it was impossible to assess biomechanical and metabolic changes of swimmers complying with a traditional over-distance-based program, a previous study using similar training programs (long-distance) on similar swimmers resulted in improvements that were at least 50% less than the improvements reported here for the stroke-based high-velocity training (9).

It is reasonable to speculate that lower intensity programs do not provide sufficient stress or the appropriate stimulus to cause optimal adaptations. This type of conventional training likely leads to decreased glycogen stores and chronic fatigue. Together, this would compromise training and competitive swim performance. This is supported by the observations that long-distance training decreases sprint swim performance, or prevents specific improvements, during the training season. Long-distance training requires a taper for recovery of performance, but the improvements are still significantly less than those reported resultant from the stroke-based, high-velocity (intensity) program used in this study. The program used in this study has built-in rest intervals within and between days of training with the most intense exercise limited to one hour per day.

The evidence presented here suggests that high-velocity training programs can be successful. Furthermore, programs which heavily rely upon dry-land strength training and long-over-distance sets should be reevaluated. Because we have no evidence to suggest otherwise, it is likely that this novel, unconventional training may be equally suited to elite swimmers as well as the more average athlete.

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Peak blood lactate and accumulated oxygen deficit as indices of freestyle swimming performance in trained adult female swimmers

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Abstract

The purpose of this study was to evaluate measures of peak post-exercise blood lactate (LA_{peak}) and accumulated oxygen deficit (AOD) as indices of freestyle swimming performance in trained adult female swimmers. These measures have been proposed to be valid indices of anaerobic energy production during exercise and competitive swimming has been reported to rely heavily on anaerobic metabolism. Specifically, this investigation examined the relation between: 1) LA_{peak} and freestyle swimming performance, 2) La_{peak} determined in a swimming flume and at poolside), 3) LA_{peak} and AOD and 4) AOD and freestyle swimming performance. Twelve well-trained female swimmers (24.9 ± 7.1 yrs old) participated as subjects. A total of five tests were conducted: 1) a discontinuous multi-stage submaximal flume swim test to determine VO_2-swimming speed relation 2) a multi-stage continuous swim test to measure maximal oxygen consumption, 3) a single stage supramaximal swim test, and 4 & 5) two performance swims (50 and 500 yards) in a 50 yard pool. Results indicated that LA_{peak} measured after a 50 yd performance swim ($LA_{peak}50$) and after a supramaximal swim test ($LA_{peak}flume$) correlated significantly with 50 yd performance time ($r = -0.53$ and -0.51, respectively). AOD was also significantly correlated with 50 yd performance time ($r = -0.68$). These data suggest that LA_{peak} and AOD are valid indices of anaerobic power during short term/sprint freestyle swimming events. None of the measures of LA_{peak} nor AOD correlated with 500 yd performance time. As such, LA_{peak} and AOD do not appear to be sufficiently sensitive indices of middle-distance swimming performance. The measures of LA_{peak} and AOD showed no inter-relation. Further research in this area should continue to focus on the underlying mechanisms associated with these two indices of anaerobic power. Finally, while LA_{peak} and AOD demonstrated significant correlations with 50 yard competitive swim performance, the relative weakness of these correlations does not warrant their use for predicting swim performance.

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Introduction

High intensity competitive swimming requires energy from both aerobic and anaerobic metabolic pathways. Quantification of the contribution of these energy systems would improve understanding of the underlying metabolic determinants of high intensity swimming performance. Such knowledge would assist in designing and evaluating training programs for swimmers. The aerobic contribution to the energy demands of dynamic exercise is now routinely measured using assessments of oxygen uptake (VO_2). In contrast, the current available methods to measure the anaerobic contribution to exercise have either proved unsatisfactory or have yet to be validated.

Blood lactate has been used as an index of anaerobic metabolism in exercising muscle. More specifically, peak post-exercise blood lactate (LA_{peak}) has been proposed as an accurate and reliable quantitative measure of anaerobic glycolysis during the preceding exercise bout (6,11,17). The use of blood lactate levels to quantify glycolytic metabolism in skeletal muscle presumes that the net accumulation of lactate in the blood is quantitatively related to the production of lactate and, therefore, anaerobic glycolysis within the muscle. This theory, however, has been criticized on the grounds that it makes unsubstantiated assumptions about lactate diffusion and distribution kinetics (18). Despite these controversial assumptions, significant correlations ($p < 0.05$) between LA_{peak} and performance times in events largely dependent on anaerobic metabolism have been demonstrated in activities such as 400 and 800 meter track running (11,16,17). Further evidence in support of LA_{peak} as an index of anaerobic power is further supported by two additional lines of evidence: 1) sprint and power trained athletes generate greater LA_{peak} values measured after sprint/high intensity exercise bouts when compared to endurance trained athletes or untrained individuals (10,13,16), 2) high-intensity training has been shown to concomitantly improve sprint performance and increase LA_{peak} (5,8,20).

More recently, the measure of accumulated oxygen deficit (AOD) during supramaximal exercise has been proposed as a measure of anaerobic capacity (14). The assessment of AOD relies on the estimation of supramaximal oxygen demand from extrapolation of the VO_2 – power output relation determined from numerous submaximal exercise bouts (14). Accumulated oxygen deficit is then defined as the difference between the predicted supramaximal VO_2 demand and the actual VO_2 measured during a bout of supramaximal exercise (14). This difference is assumed to be the anaerobic contribution to the exercise bout. The determination of AOD has also been criticized for underlying assumptions (i.e., linearity) regarding the extrapolation of submaximal VO_2 – power output relation to determine supramaximal energy demand (3). As with LA_{peak}, significant correlations between AOD and performances dependent on anaerobic metabolism have been demonstrated in running (17,22) and cycling (4). Similarly, higher AOD values have been reported in sprint/power athletes during sprint/high intensity exercise when compared to endurance trained or sedentary individuals (13,15,19). However, the relation between AOD and freestyle swimming performance has yet to be established.

In summary, LA_{peak} and AOD have been proposed as valid indices of anaerobic/glycolytic metabolic activity and exercise performance. Implicit with this hypothesis is the expectation that these measures would not only be correlated with freestyle swimming performance but with each other as well. Therefore, this study used trained adult female swimmers to evaluate the relation between: 1) LA_{peak} and freestyle swimming performance, 2) AOD and freestyle swimming performance, 3) LA_{peak} determined experimentally in a swimming flume and LA_{peak} measured after performance swims in a 25 yard pool and 4) the measures of LA_{peak} and AOD.

Methodology

Subjects

Twelve well-trained female swimmers volunteered to participate in this investigation. Subject characteristics are presented in Tables 1 and 2. Subjects were recruited from a

Table 1. Subject Characteristics

Variables	**Mean ± SD**
N	12
Age (yrs)	24.92 ± 7.14
Height (cm)	169.20 ± 5.70
Weight (kg)	63.26 ± 6.55
% Body Fat	21.53 ± 4.33
Years of swim training	15.33 ± 6.15
Yards trained per week	10,416 ± 10,112

Table 2. Subjects' self-reported swim training history and personal records (PR)

Subject	Yards Trained per Week	Years of Training	PR for 50yds (sec)	PR for 500 yds (min:sec)
EC	16,000	15	28.0	5:52
CI	12,000	16	-	-
LJ	5,000	10	29.0	-
CK	5,000	16	27.0	7:05
ML	40,000	5	28.7	4:36
AM	6,000	14	26.7	6:15
LP	12,000	27	28.8	6:13
JP	6,000	14	25.7	6:21
RR	3,000	15	29.5	6:32
CR	7,000	25	24.2	5:08
MS	9,000	18	27.9	5:35
CS	3,000	9	28.0	-

pool of individuals capable of swimming (freestyle) 50 yards in 30 seconds or less and/or 500 yards in 7 minutes or less. Subjects completed swim and medical history questionnaires and gave their written consent prior to their participation in the study. All experimental procedures were approved by the University of Pittsburgh's Institutional Review Board for Human Subjects Experimentation.

Experimental Design

All subjects underwent an orientation trial prior to the experimental trials. Subsequent to the orientation trial, each participant performed a total of 5 tests: 1) a discontinuous multi-stage submaximal swim test to determine the swimming speed-VO_2relation for the prediction of supramaximal oxygen demand, 2) a multi-stage continuous swim test to measure VO_2max_{swim}, 3) a single stage supramaximal swim test to measure LA_{peak} and AOD, and 4 & 5) two all-out swims in the pool (50 and 500 yards) to measure performance time and post competition LA_{peak}. The first three tests were conducted in a swimming flume (SwimEx Systems Inc., Warren RI, Model # SX600T) and the performance swims were conducted in the University of Pittsburgh swimming pool. The order of testing was randomized except for the supramaximal test. This was because the speed of the supramaximal test was determined from data generated by the submaximal and VO_2max_{swim} tests. The individual tests were separated by at least one week. Subjects were instructed to maintain their normal training regime during this time. With the exception of one individual, none of the subjects were training for competition. Most (10) of the subjects had competed at the high school or college level but now trained largely for fitness. As such, there was little variation in training routine from week to week.

Orientation Trial

Upon arrival at the swimming flume, weight, height, percent body fat, were determined for each subject. For descriptive purposes, percent body fat was determined using skinfold and gluteal circumference measures (9). Following completion of the anthropometric measurements, subjects practiced swimming in the flume. In order to become familiar with the unique aspects of swimming in the flume, subjects swam in the flume without respiratory/metabolic equipment during the initial orientation trial. After a brief rest, subjects then swam at four submaximal speeds using respiratory/metabolic instrumentation. This served two purposes: 1) to allow the subject to become familiar with swimming in the flume while wearing a mouthpiece/face mask and heart rate monitor, and 2) to allow the investigators to assess the subjects' responses to swimming in the flume at various speeds. A specially designed mouthpiece/face mask worn by the subjects was connected to an open-circuit spirometry system (SensorMedics, MMC Horizon) so that respiratory/metabolic data could be collected. Heart rates were measured every minute with a Polar heart rate monitor. This respiratory/metabolic instrumentation was used during all tests conducted in the flume with the exception of the supramaximal swim test.

Submaximal Swim Test

The submaximal test consisted of six swims of three minutes duration performed in a stationary position against progressive speeds of water current generated by the flume. Each swim was separated by five minutes rest. The initial speed, as determined from the orientation trial, was such that it elicited a heart rate of 120 to 130 beats per minute and/or a VO_2 of not more than 25 ml · kg^{-1} · min^{-1}. Swimming speed was then increased an average of 0.10 meter · sec^{-1} each stage. VO_2 was reported in 20 second averaging intervals. Steady state VO_2 for each stage was defined as a difference of 2 ml · kg^{-1} · min^{-1} or less between the last three 20 second averaging intervals. Steady state VO_2 for each stage was recorded as the average of the last three 20 second averaging intervals. Steady state VO_2 was then plotted as a function of swimming speed and a regression line drawn for the purpose of predicting supramaximal VO_2 demand (Figure 1).

VO_2max_{swim} Test

The VO_2max_{swim} test employed a continuous graded exercise test (GXT) to exhaustion. The protocol for the GXT was adapted from that employed by Wakayoshi et al. (21).

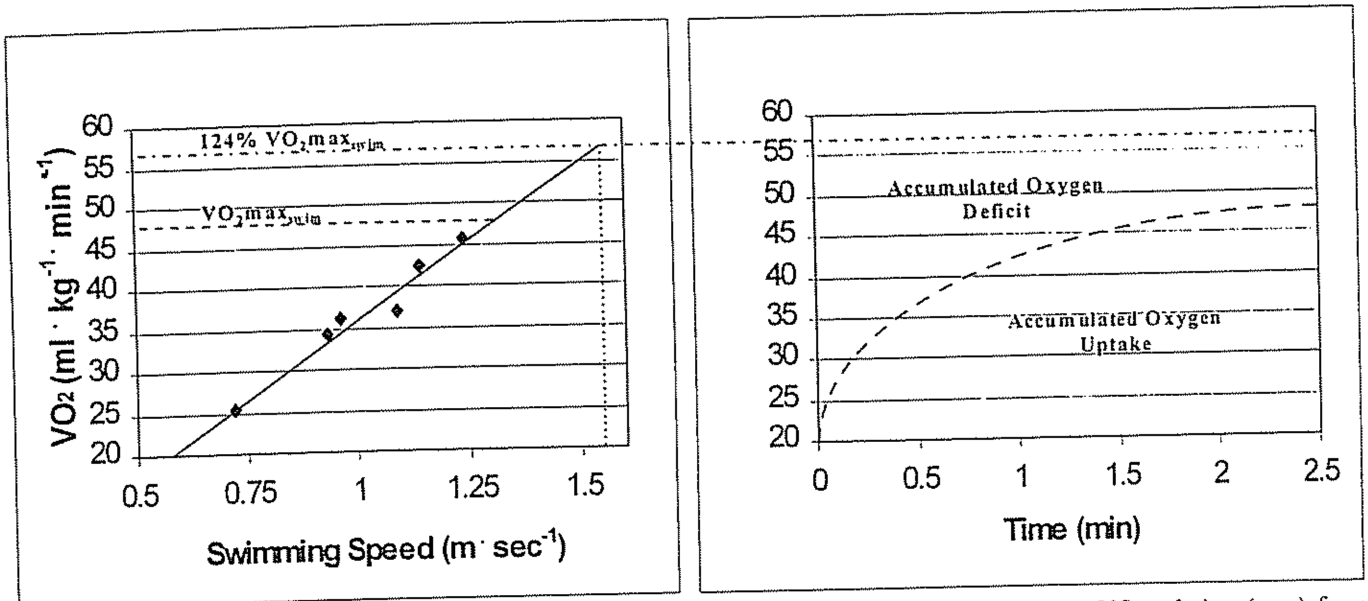

Figure 1-Steps in the determination of accumulated oxygen deficit: 1) determination of speed - VO_2 relation (——) from submaximal swim test, 2) measurement of VO_2max_{swim} (------), 3) determination of supramaximal VO_2 demand (·---) and swimming speed (·······), 4) measurement of accumulated oxygen uptake (area under curve) and 5) calculation of AOD: difference between the estimated supramaximal oxygen demand and the accumulated oxygen uptake (- - - -). Graphs represent data from subject LP.

Subjects performed a 10 minute warm-up swim beginning at approximately 40% of their age-predicted maximal heart rate (APMHR) and progressing to approximately 85% of their APMHR. Subjects then rested until their heart rate was less than 100 bpm. The first exercise stage began at the speed corresponding to approximately 85 per cent of the subjects' age APMHR. The first exercise stage was two minutes in duration. Thereafter, swimming speed was increased 0.10 m $\cdot$ sec^{-1} every 30 seconds until exhaustion.

Supramaximal Swim Test

The supramaximal swim test consisted of a single stage exhaustive swim performed in the flume at a speed corresponding to 124 ± 7.6% of the subjects' VO_2max_{swim} for the measurement of AOD and LA_{peak}. This intensity was determined from pilot work and allowed subjects to swim for at least two minutes, an important criteria for the determination of AOD (14). The speed for this test was then calculated from an extrapolation of the VO_2-swimming speed relation determined from the submaximal swim test (Figure 1).

During the test, respiratory gases were collected in 150 liter Douglas bags. Immediately upon termination of the test the gases were taken to the University of Pittsburgh Medical Center, Department of Preventive Cardiology. There, the gases were analyzed for O_2, CO_2, and N_2 concentration with a mass spectrometer. Gas volume was measured with a Kofranyi-Michaelis gasometer. Accumulated oxygen deficit was calculated as the difference between the estimated oxygen demand for the supramaximal swimming bout and the accumulated oxygen uptake measured during the test. AOD was expressed in Liters (STPD).

Immediately after the test, subjects were asked to rest quietly, seated on the edge of the flume. A 3ml blood sample was taken five minutes after the conclusion of the swimming bout for the determination of LA_{peak}*flume*. Blood was analyzed for lactate concentration with a YSI 2700 biochemical analyzer. LA_{peak} was expressed as mmol $\cdot$ L^{-1}.

Competitive Swimming Performance Tests

Two competitive swimming performance tests, 50 and 500 yards, were performed on separate days in the Trees Hall pool at the University of Pittsburgh. The order of testing was randomized. Each test began with a 500 yard warm-up swim followed by five minutes rest or until the subjects heart rate was below 100 bpm. At the end of the rest period, the subject performed either a 50 or 500 yard freestyle swim with instructions to perform the swim with a maximal effort, as in competition. All performance swims were from a push start. All swims were hand timed and performance times were recorded to the nearest tenth of a second. Immediately after each performance swim the subject was instructed to rest quietly, seated on the edge of the pool. After five minutes of rest, a 3 ml blood sample was taken by venipunture for determination of LA_{peak}*50* (after the 50 yd swim) and

$LA_{peak}500$ (after the 500 yd swim). The blood samples were analyzed for lactate concentration with a YSI 2700 biochemical analyzer.

Statistical Analysis

Correlation analysis was used to determine the relation between: 1) peak post-exercise blood lactate (LA_{peak}flume, $LA_{peak}50$, and $LA_{peak}500$) and freestyle swimming performance (50 and 500 yards) in trained adult female swimmers, 2) AOD and freestyle swimming performance (50 and 500 yards) in trained adult female swimmers, 3) peak post-exercise blood lactate determined experimentally in a swimming flume (LA_{peak}flume) and LA_{peak} measured following performance swims of 50 yards ($LA_{peak}50$) and 500 yards ($LA_{peak}500$), and 4) the measures of La_{peak} and AOD. Statistical significance was accepted at the $p < 0.05$ level of confidence. SPSS for Windows^R statistical software was used to perform the statistical analysis.

Findings

The results of the laboratory/flume tests and performance swims are presented in Table 3. To validate the "all-out" nature of the competitive performance swims, post-swim heart rates were compared with those obtained at VO_2max_{swm}. Heart rates were 181.9 ± 12.3, 175.5 ± 22.9, and 177.7 ± 16.8 for VO_2max_{swm}, 50 yard and 500 yard competitive swims, respectively. Paired-samples T-tests revealed no significant difference between the heart rates for VO_2max_{swm} and either 50 yard ($p = 0.404$) or 500 yard ($p = 0.542$) competitive performance swims.

Table 3. Test Results

Tests	Results (Mean ± SD)
VO_2max_{swim}	46.19 ± 7.31 $ml \cdot kg^{-1} \cdot min^{-1}$
50 yard freestyle	30.37 ± 1.36 sec
500 yard freestyle	6:31 ± 00:27 min:sec
$La_{peak}50$	5.88 ± 2.44 mmol/L
$La_{peak}500$	7.76 ± 2.29 mmol/L
La_{peak}flume	12.04 ± 2.48 mmol/L
AOD	2.72 ± 1.11 L

Significant correlations were found between both measures of LA_{peak} ($LA_{peak}50$ and LA_{peak}flume) and time in the 50 yd freestyle competitive performance swim ($r = -0.528$, $p = 0.039$, SEE = 1.21 and $r = -0.514$, $p = 0.044$, SEE = 1.23, respectively). Figure 2 presents a scatter plot of the relation between $LA_{peak}50$ and 50 yard competitive performance swim time. The power to predict 50 yard performance time was almost identical for $LA_{peak}50$ and LA_{peak}flume. Performance time predicted from $LA_{peak}50$ (performance time = -0.295 ($LA_{peak}50$) + 32.1) and LA_{peak}flume (performance time = -0.283 (LA_{peak}flume) + 33.775) were within 0.89 ± 0.64 and 1.01 ± 0.51 seconds of actual performance time, respectively. These two measures of LA_{peak} not only correlated significantly with 50 yard performance time but with each other as well ($r = 0.709$, $p = 0.005$, SEE = 1.81). No significant correlations were found between LA_{peak}flume or $LA_{peak}500$ and performance time in the 500 yd freestyle performance swim ($r = 0.178$, $p = 0.290$ and $r = 0.152$, $p = 0.318$, respectively). Although LA_{peak}flume and $LA_{peak}500$ were significantly correlated with each other ($r = 0.721$, $p = 0.004$, SEE = 1.66), neither was predictive of 500 yard performance time.

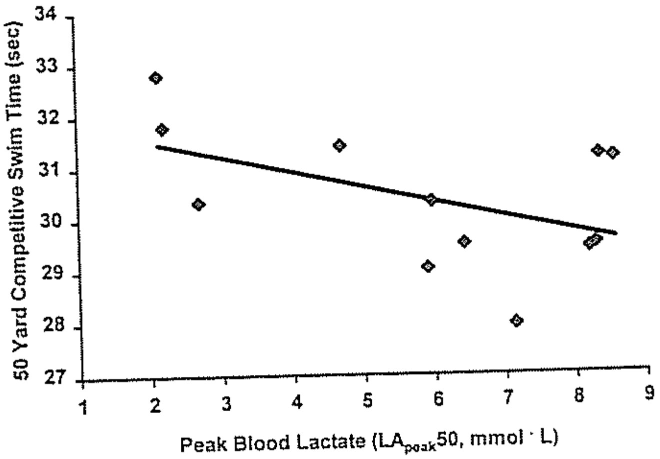

Figure 2. Relation between peak blood lactate and 50 yard competitive swim time. Solid line represents line of best fit determined by linear regression.

Accumulated oxygen deficit was significantly correlated with time in the 50 yd freestyle performance swim ($r = -0.676$, $p = 0.016$, SEE = 1.12). Figure 3 presents a scatter plot of the relation between AOD and 50 yard competitive performance swim time. Performance time predicted from AOD (performance time = - 0.877 (AOD) + 32.923) was within 0.80 ± 0.67 seconds of actual performance time. However, AOD did not correlate with performance time in the 500 yard freestyle swim ($r = -0.379$, $p = 0.14$) or any of the measures of blood lactate ($r = 0.118$, $p = 0.373$, $r = -0.489$, $p = 0.076$, and $r = 0.086$, $p = 0.407$ for $LA_{peak}50$, $LA_{peak}500$ and LA_{peak}flume, respectively.

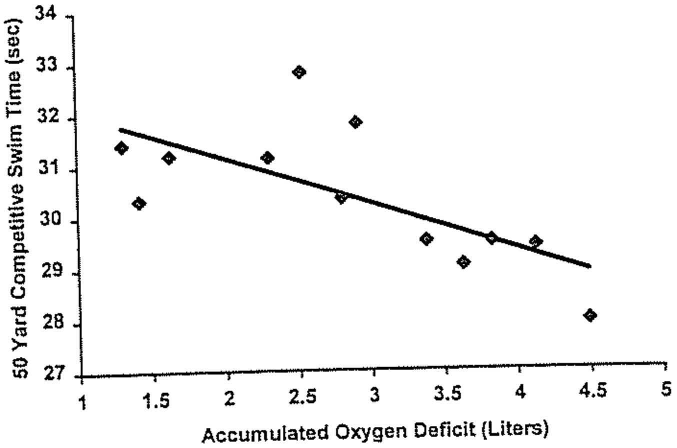

Figure 3. Relation between accumulated oxygen deficit and 50 yard competitive swim time. Solid line represents line of best fit determined by linear regression.

Discussion

The purpose of this study was to determine whether LA_{peak} and AOD are valid indices of freestyle swimming performance in trained adult female swimmers. Previously, both of these measures have been demonstrated to be correlated with performance in sprint and middle distance running events (11, 17, 22). To our knowledge, however, this was the first attempt to evaluate these measures as correlates of exercise performance using a swimming model. The results indicate that LA_{peak} measured after an exhaustive/all-out swim of three minutes or less in duration is modestly predictive of 50 yard sprint performance in trained adult female swimmers. The energy required for a 50 yard performance swim is supplied primarily by the anaerobic metabolic systems (12). As such, these results suggest that LA_{peak} may be a valid index of swimming performance relying heavily on anaerobic glycolytic energy production. Further, it appears that this measurement is equally valid in a poolside or laboratory setting.

In contrast, neither of the two independent measures of peak post-exercise blood lactate (LA_{peak}500 and LA_{peak}flume) were predictive of 500 yard freestyle swimming performance. Based on its correlation with 50 yard freestyle swimming performance, LA_{peak} may be a valid index of anaerobic power during high intensity swimming. Because middle-distance swimming relies at least in part on energy derived from anaerobic glycolysis, it would be expected that LA_{peak} would be predictive of 500 yard freestyle swimming performance. It has been postulated that only half of the total energy demands of the 500 yard freestyle are provided by anaerobic metabolism (12). However, this is unsupported by controlled scientific studies. In the present study, measures of aerobic power, specifically VO_2max and VO_2 at blood lactate concentration of 4 mmol/L, were significantly correlated with 500 yard performance time (r = -0.528, p = 0.039 and r = -0.621, p = 0.016, respectively). In addition, an examination of the present investigation's subject training logs revealed that only two of twelve subjects were engaging in any type of anaerobic training. It is possible that performance in the 500 yard freestyle, in this subject cohort, may have been even less dependent on anaerobic metabolism than previously reported. Finally, it is important to note that the measures of LA_{peak} accounted for only approximately 27 percent of the variation in performance times in the 50 yard freestyle swim, which is almost exclusively dependent on anaerobically derived energy. A possible confounding variable in the measurement of peak lactate was the timing of the blood draw. While it is generally agreed that blood lactate levels generally peak between 3 and 7 minutes post-exercise, there is considerable inter-individual variation. As such, it is possible that LA_{peak} was not a sufficiently sensitive index to measure inter-subject differences in the anaerobic contribution to 500 yard freestyle swimming performance in this particular cohort.

The present findings indicate that AOD measured in a swimming flume may be a valid index of high-intensity freestyle swimming performance in trained adult female swimmers. The results indicate that AOD measured in a swimming flume, using the protocol described above, is modestly predictive of 50 yard sprint performance in trained adult female swimmers. However, as with the measures of LA_{peak}, AOD was not correlated with performance time in the 500 yard freestyle swim. Green et al. (7) previously observed that ". . . performances on tasks partially determined by anaerobic capacity (or underlying mechanisms) are not always associated with a larger AOD". The previous discussion regarding the lack of a relation between the measures of LA_{peak} and middle-distance swimming performance would seem to apply here as well. The lack of correlation between the measures of LA_{peak} and AOD in the present study has been observed previously (2). These authors suggested the absence of a correlation was due to the presumption that measures of LA_{peak} are partially determined by non-anaerobic metabolism, specifically lactate removal. Regardless, it is beyond the scope of the present investigation to speculate as to the reason for the lack of correlation between these two indices of anaerobic power. Future research should continue to investigate the underlying mechanisms associated with each of these measures.

In conclusion, these data suggest that measures of LA_{peak} and AOD may be valid indices of anaerobic capacity and performance during short term/sprint freestyle swimming events. Further, it appears that the predictive power of LA_{peak} measured poolside is equal to that measured in a laboratory setting. The measures of LA_{peak} and AOD were not predictive of middle-distance swimming performance in this subject cohort, possibly due to a lack of sensitivity. The measures of LA_{peak} and AOD showed no inter-relation. As such, further research in this area should continue to focus on the underlying mechanisms associated with these two measures of anaerobic power.

Application

The measures of LA_{peak} and AOD demonstrated small but significant correlations with 50 yard competitive swim performance. However, the relation between these measures and swimming performance also demonstrated significant inter-subject variability. In addition, the lack of correlation between the measures of LA_{peak} and AOD leave some doubt as to the validity of these measures as indices of anaerobic power. Therefore, based on these data, it cannot be recommended that measures of LA_{peak} or AOD be used as predictors of freestyle swimming performance.

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Body temperature homeostasis during a 40 km open water swim

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Abstract

The purpose of this study was to monitor body temperature during a 40 km (24.8 miles) swim in cool water using a commercially available telemetric device. Subjects, comprised of 13 males and 4 females ranging in age from 20 to 41 years, were participants in La Traversée du Lac St. Jean – an international long distance swim competition. On race day, water temperature in the lake ranged from 18.3 to 22.4 °C (64.9 to 72.3 °F). Internal body temperatures was monitored throughout the race with the CorTemp system (model 4000, HTI Technologies, St Petersburg, FL) which consists of a capsule containing a temperature sensitive quartz crystal that transmits a signal to a remote receiver. Subjects swallowed the thermometer pill 2 h prior to the race. Swim times averaged 628 ±40 minutes for the males and 666 ±36 minutes for the females. Pre-swim to post-swim oral temperature decreased by 2.0 °C (37.1 ±0.6 to 35.1 ±1.1) and tympanic temperature also decreased by 2.0 °C (36.2 ±0.2 to 34.2 ±0.7). Using the CorTemp telemetry system, the mean core temperature was 37.5 ±0.3 °C (99.5 °F) pre-swim and 37.3 ±0.8 °C (99.1 °F) post-swim. Oral and tympanic temperatures were significantly lower than the CorTemp following the swim. These results indicate that core temperature measured via the CorTemp system was able to be maintained during the 40 km swim in cool water.

KEY WORDS - Distance, Body temperature, Athletes, Swimming, Telemetry of temperature in cool water.

Introduction

Hypothermia is a challenge for competitors during prolonged swims in cool water. When core temperature falls, oxygen consumption increases and swimming velocity decreases. Maintenance of core temperature may relate to body composition since fat tissue can insulate the body during cold exposure. Monitoring core temperature of athletes during a race of any kind, specifically endurance swimming events, presents a variety of methodological problems. Traditional techniques for measurement of core temperature in laboratory and clinical environments are not appropriate for use in most athletic competitions. While esophageal and rectal temperature are reliable indices of core temperature, they are invasive measurements that require a wire connection between the sensor and monitoring-recording device. The frequency of calibration and the physical discomfort of intrusive thermistor probes are limitations that are not tolerated by athletes during competition. The invention of an ingestible temperature pill telemetry system has given researchers a new avenue to explore the monitoring of core temperature with athletes. The CorTemp system was first introduced by the National Aeronautics Space Administration (NASA) to monitor hypothermic and hyperthermic body temperatures during space travel. Recent studies have established the validity and reliability of the CorTemp system to monitor core temperature during rest and exercise in warm or neutral ambient conditions (6,9,14) and during cold exposure (7).

The aim of this study was to monitor core temperature during a 40-km (24.8 miles) swim at "La Traversée Internationale du Lac St-Jean" that takes place in Quebec, Canada. This international swimming competition is known

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to be particularly strenuous because of the lake's cold temperatures. In the past, the medical staff has frequently reported cases of hypothermia (2).

Methods

The subjects were 17 professional swimmers (13 men and 4 women) who competed at the 1997 edition of the "La Traversée Internationale du Lac St-Jean" – a 40 km swimming competition. The range of age was 20 to 41 years. This international event included participants from 8 countries: Argentina, Brazil, Canada, Czech Republic, Egypt, Germany, Holland, and the U.S.A. This event has been rated as the 6th most challenging endurance event in the world as rated by Outside magazine. The participants are among the best endurance swimmers in the world. The swimmers voluntarily consented to participate after being informed of the purpose, procedures, risks and benefits of the research, which was approved by a Research Ethics Committee at McGill University.

The initial 4.11 km (2.55 miles) of the race occurred in a river at a temperature of 18.3°C. The next 35.89 km (22.29 miles) were in a 1000-km² lake at a mean temperature of 21.9°C. On the day of competition, the air temperature was 23°C with wind velocity varying from 20 to 40 km/h (12.4 to 24.8 miles/h). The swimmers wore only swim suits as the rules of the competition stipulated that the competitors could not wear suits. This rule increases the risk of hypothermia for the competitors.

On the day prior to the competition, height, weight and skinfolds were recorded. Three skinfold sites (triceps, subscapular, abdomen) were measured and used to predict percent fat (5, 13). The physical characteristics of the subjects are listed in Table 1. Compared to the general population, the men were average in fatness while the women were relatively lean.

To minimize distractions on race day, oral, tympanic and rectal temperatures were taken on the day prior to competition. These measurements were taken in late afternoon, at the approximate finishing time of the swimmers in order that changes in core temperature could be interpreted with respect to diurnal variation in temperature. The resting core temperature exhibits a circadian rhythm averaging about 0.6 to 0.7°C higher at 16:00 hours compared to 4:00 hours (15). Oral temperature was measured by placing a mercury-in-glass thermometer under the tongue for 2 minutes. Tympanic temperature was measured using an infrared tympanic thermometer. The crystal light of the thermometer sometimes malfunctioned due to the high temperature and humidity in the medical room. Rectal temperature was measured using a mercury-in-glass thermometer that was inserted 7 cm past the anal sphincter. The temperature in the medical room did not affect body temperature.

Two hours prior to competition, the athletes swallowed an ingestible temperature pill so that core temperature could be monitored via telemetry throughout the race. At the start of the swim, the CorTemp pill was probably located in the small intestine and by the end of the swim was probably located in the large intestine. Temperature in the small and large intestine is more uniform than in the upper portion of the gastrointestinal tract. The magnitude of fluctuation attributed to pill movement through the small and large intestine has been estimated at 0.2 - 0.3°C (6). During the race, the swimmers consumed liquid nourishment at various temperatures. The frequency and volume of fluids consumed were not recorded. The CorTemp pill was ingested two hours prior to competition so that warm beverages in the stomach would not influence it.

The telemetric temperature pill was a disposable capsule (silicon-coated, 10 mm in diameter and 27 mm in length) containing a temperature quartz crystal oscillator with a silver

Table 1: Characteristics of the subjects.

	MALES (n = 13)		FEMALES (n = 4)	
VARIABLE	Mean ± SD	Range	Mean ± SD	Range
Age (yrs)	25.9 ± 5.4	21 – 41	28.8 ± 7.1	20 – 35
Weight (kg)	87.6 ± 3.8	75.1 – 96.5	62.8 ± 6.4	55.7 – 69.3
Height (cm)	179.9 ± 5.7	166.3 – 187.6	167.1 ± 8.1	157.7 – 176.2
Body Fat (%)	14.9 ± 2.5	11.5 – 20.4	12.9 ± 0.7	12.4 – 13.9
B.S.A. (m²)	2.01 ± 0.08	1.84 – 2.24	1.69 ± 0.14	1.54 – 1.84
B.M.I.(kg/ m²)	26.3 ± 1.7	22.5 – 28.4	22.5 ± 0.4	22.2 – 23.0

B.S.A. = Body Surface Area
B.M.I. = Body Mass Index

oxide battery (CorTemp, Human Technologies, Inc., St. Petersburg, FL). This sensor transmitted a continuous, low frequency radio wave to an external receiver that was downloaded to a computer after data collection. Each pill was individually calibrated by the manufacturer and had its own frequency that varied with temperature. The accuracy of the CorTemp sensor is ± 0.1°C. The accuracy is maintained over a temperature range of 0°C to 50°C. A linear relationship exists between signal frequency and temperature using the CorTemp system. The correlation exceeds 0.999 (9). The CorTemp sensor is capable of tracking body core temperature for 72 hours following ingestion.

In the gastrointestinal tract, the CorTemp sensor vibrates at a frequency that varies according to body temperature. The signal transmission method is near field magnetic link. The magnetic flux signal is transmitted through the body to the CorTemp recorder. The data are stored in solid state memory. The recorder was capable of storing up to 10000 data points. The output was 0-5 volt analog or 4-20 ma current loop.

As opposed to dry land monitoring of temperature with the CorTemp system in an event such as a marathon, the environmental conditions of this endurance swimming event required additional planning. Due to interference of signal transmission by the water, the swimmers had to be approached by boat to within 1 - 2 meters. A pole designed to hold the CorTemp receiver was lowered above the swimmer's lumbar region so that the temperature signal from the swimmer could be registered. The core temperature of each swimmer was taken every two hours during the competition. The choppy water conditions demanded expertise by the boat driver. Figure 1 illustrates how the receiver was placed over the swimmer.

Legend for Figure 1.
Telemetry of core temperature using the CorTemp receiver that was held above the swimmer and relayed to the analyzer on the boat deck.

Upon race completion, oral, tympanic and core temperatures were measured within the first five minutes of exiting the water and every five minutes thereafter, until core temperature returned to normal values. All swimmers had returned to normal values by 10 minutes.

The study utilized a repeated measures design in which subjects served as their own control. Temperature measurements with the CorTemp system were made pre-swim, post-swim and every two hours during the swim. Results are presented as means ± S.D. and analysed with a repeated measures ANOVA with $p < 0.05$ for significance.

Results

Swim time for the 40-km (24.8 miles) event averaged 628 ± 40 minutes for the men and 666 ± 36 minutes for the women. Pre-swim rectal temperatures are shown in Figure 2a and 2b. The athletes refused post-swim measurement of

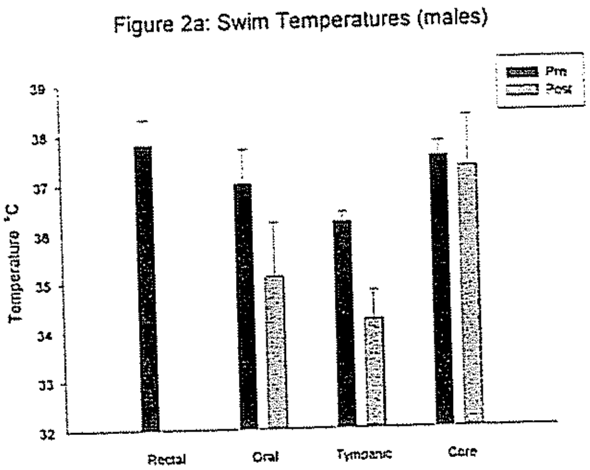


Figure 2a: Swim Temperatures (males)

Legend for Figure 2a.
Swim Temperatures (males).

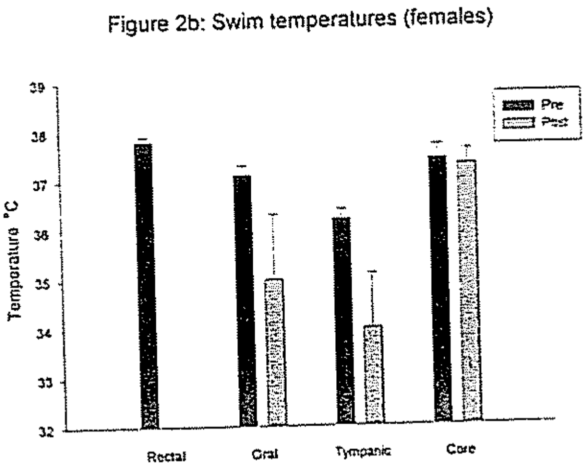


Figure 2b: Swim temperatures (females)

Legend for Figure 2b.
Swim Temperature (females)

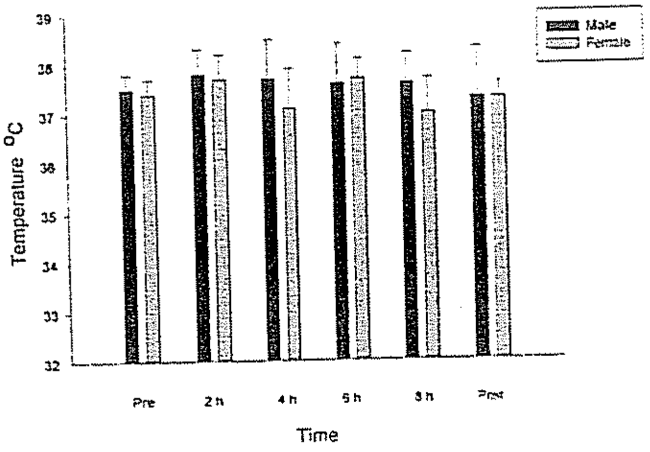
rectal temperature. Pre- and post-competition oral, tympanic and core temperatures are illustrated in Table 2. Tympanic and oral temperature were significantly decreased by 2.0°C following the swim for the total group.

Table 2: Pre and post swim temperatures

Temp.	Rectal	Mouth		Tympanic		Core	
Males	**Pre**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
1	37.8	37.4	36.0	36.1	35.1	37.3	38.1
2	37.6	37.6	35.0	36.3	34.2	36.9	35.9
3	37.8	37.5	34.4	36.1	34.6	37.3	37.0
4	38.0	37.4	37.2	36.2	34.0	37.3	37.3
5	38.2	37.2	34.6	36.3	34.3	37.7	37.8
6	37.8	37.2	33.4	36.4	34.3	37.2	37.7
7	36.4	36.6	34.8	36.2	33.8	37.6	38.1
8	38.0	36.8	35.0	36.1	34.7	37.6	38.0
9	38.1	35.0	34.8	36.3	33.8	37.2	36.9
10	37.9	37.0	35.0	36.5	34.4	37.4	35.7
11	38.2	37.2	34.0	36.5	32.6	37.9	35.8
12	38.0	37.2	35.4	36.5	34.1	37.9	38.7
13	37.8	37.4	37.2	35.7	34.7	37.6	37.4
Mean	37.8	37.0	35.1	36.2	34.2	37.5	37.3
S. D.	0.5	0.7	1.1	0.2	0.6	0.3	1.0
Females							
14	37.8	36.9	33.8	35.9	34.6	37.4	37.0
15	37.9	37.0	34.8	36.2	32.4	37.7	37.4
16	37.8	37.4	36.8	36.1	34.8	37.1	37.6
17	37.8	37.2	34.6	36.4	34.2	37.5	37.3
Mean	37.8	37.1	35.0	36.2	34.0	37.4	37.3
S. D.	0.1	0.2	1.3	0.2	1.1	0.3	0.3

Data at two hours intervals for telemetry with the CorTemp pill are displayed in Figure 3. There was no significant difference in core temperature between pre- and post-competition. Core temperature did not show any significant variation during the race. Only three swimmers had core temperatures that dropped below 36.0°C during the swim, but none of them had hypothermia as defined by a core temperature below 35°C. The body fatness and surface area of these three swimmers were similar to the mean values of the other swimmers and thus could not explain the drop in core temperature. The swim velocity for these three swimmers was not reduced even though core temperature dropped.

Figure 3: Telemetry of Core Temperature



Legend for Figure 3
Telemetry of core temperature

All swimmers returned to their normal core temperature within 10 minutes after the race. The competitors were unwilling to wait in the medical room until their oral and tympanic temperatures had returned to normal.

Discussion

The purpose of this study was to monitor core temperature during a long distance swimming competition in cool water. Core temperature usually rises when exercise is performed in thermoneutral water temperatures. Exercise in cold water poses a thermal challenge for swimmers. Because this study was conducted on the day of a major endurance competition, certain variables could not be controlled (weather, water temperature). Another element that could not be predicted was the response of the infrared tympanic thermometer. Indeed, we observed that this type of infrared tympanic thermometer was sensitive to ambient heat and humidity.

Water has a higher thermal capacity than air. During water immersion conductive and convective heat transfer is 70-fold greater than in air at the same temperature (4). Thus when water temperature is cool, long-distance swimmers loose considerable body heat (11). Low body temperature may impair myocardial contractility and limit maximal heart rate (1) thereby lowering maximal cardiac output and VO_2 max. Cold stress must be sufficient to reduce core temperature by 0.5°C before VO_2 max is lowered (12). Anthropometric factors explain much of the variability among individuals in their capability to maintain normal body temperature during cold exposure (16).

When taken continuously, oral temperature has been shown (8) to be an accurate estimate of core temperature. However, following 10 hours of swimming, it was not appropriate to keep the swimmers from eating and drinking. The consumption of food and drink altered oral temperatures and made comparisons with the CorTemp system inaccurate.

The CorTemp pill has been used previously with runners, cyclists and swimmers in a pool setting to monitor core temperature. Significant correlations have been found with esophageal and rectal temperature (9, 14). This study is the first to successfully monitor via telemetry the core temperature of swimmers during a long distance competition.

As recommended by Kolka et al. (6), the swimmers ingested the CorTemp pill two hours prior to the competition in order to avoid changes in temperature related to drinking or eating. During the race, core temperature was stable for 14 of the 17 swimmers. O'Brien et al (9) concluded that the CorTemp pill is a valid method for measurement of core temperature in humans during conditions of both decreasing as well as increasing body temperature. Our experience with the CorTemp system supports its use for telemetry of core temperature during long distance swimming in cool water.

The oral and tympanic temperatures of the swimmers were 2°C lower post-competition compared to pre-race values. Previous research (7) has shown that cold exposure lowers these measurements relative to core temperature and makes them susceptible to cooling. For this reason, we conclude that both oral and tympanic temperatures are not an appropriate measure of core temperature in a cool water environment.

Application

Hypothermia is a major medical concern during the cold water swimming competition of "La Traversée Internationale du Lac St-Jean". Indeed in previous races, some swimmers were reported to have experienced marked hypothermia (<34°C) and/or hypoglycemia (2). In Dulac's 1987 study, the water temperature was 18.5°C. The leaner subjects (body fat < 10%) were unable to complete the race, with 7 of the 10 non-finishers developing hypothermia (2). The leanest subject in our study had 11.5% fat. In the 1998 race, 13 swimmers were removed from the water during the race with 8 swimmers displaying symptoms of hypothermia. Physicians involved in medical coverage, as well as coaches of long distance swimmers competing in cold water, should be aware that oral or tympanic measurements might not accurately reflect the core temperature. Rectal temperature is often inferred as the best measurement for monitoring body core temperature, but during athletic competition, it is often not practical nor accepted by most competitors during international competitions. Cultural differences are a factor that influence acceptance in the measurement of rectal temperature.

This study indicated that core temperature measured via the CorTemp system was feasible during a long distance swimming competition in a lake of 1000 km². It is a useful method to monitor core temperature in swimming competitions in an outdoor setting. The CorTemp system is easy to set up and requires minimal training to use the instrument. It provides important information on the body core temperature of the swimmer that can help the medical staff to give better care by prevention of major hypothermia. The CorTemp system is a tool that can assist the medical staff and coaches to intervene before serious complications develop.

The weakness of the CorTemp system for monitoring the core temperature of swimmers is the range of signal transmission. It was necessary for a boat to approach the swimmer so that the signal could be transmitted from the swimmer to the recorder located in the boat. Figure 1, page 28, illustrates how close the boat must approach the swimmer.

Coaches and trainers may find the CorTemp system as beneficial to help swimmers to improve their tolerance and performance in cold water. Knowledge of the core temperature and the factors that influence these variations may bring about changes to the training program or training environment.

Further research needs to be done using the CorTemp system. For example, it is important to understand how consumption of warm and cold drinks may influence the variation in temperature along the gastrointestinal tract. Also, the CorTemp pill could be used to investigate the protective role of body fat, alimentation and level of fitness in preserving core temperature during cold water swimming. In our experience, swimmers accept the CorTemp pill to monitor core temperature since the temperature pill does not distract during training or competition. None of the athletes that we monitored with the CorTemp system reported any discomfort nor side effects.

We conclude that core temperature as measured by an internal telemetric system was maintained during a 40 km swim in cool water ranging from 18 to 23°C. Also, physicians involved in medical coverage, as well as coaches of long distance swimmers competing in cold water, should be aware that oral or tympanic measurements may not accurately reflect the core temperature.

Acknowledgments

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Dive depth and water depth in competitive swim starts

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Abstract

This study investigates the depths achieved by junior elite swimmers performing competitive dive starts. Dive starts of 54 swimmers entering water of 2 m depth were examined to produce data of typical dive depths. Thirty-six of these participants also performed a competitive start into water 1.2 m deep. A comparison of dive depth in both water depths was made. For all dives, swimmers were asked to perform their typical competitive dive start. No instructions were given regarding dive depth. All dives were video-recorded from above and below water. Maximum depth; velocity at maximum depth; distance at maximum depth; angle of entry and flight distance were measured. Competitive swimmers performed shallower dives when entering shallow water. Shallower dives (maximum depth 0.09 m shallower, p=.000) were achieved without significant differences in any other parameters (distance at maximum depth, p=.022; velocity at maximum depth, p=.635; entry angle, p=.070; flight distance, p=.557). As velocity remained unchanged, coaches can instruct swimmers to perform shallower, safer dives without performance disadvantage.

INDEX TERMS: swimming, diving, swimming starts, competitive swimming

Introduction

The ability to perform efficient, effective and safe competitive dive starts is vital to competitive swimmers. Races can be won by as little as 0.01 s, and it is claimed that enhanced starting techniques can make up to 0.1 s improvement in performance times (10). The Fédération Internationale de Natation Amateur (FINA) is the international body governing competitive swimming, and stipulates that a minimum water depth of 1.2 m is necessary for swimming competitions where dive entries are performed from 0.75 m high standard starting blocks (17). However, this stipulation is based on field experience only, rather than scientifically based experimental evidence (13).

The incidence of spinal cord injury caused by shallow water diving in some regions of the world is relatively high, accounting for 21% of all traumatic spinal cord injuries reported in Poland from 1965-1978 (8), and 11% in Australia in the twelve months to June 1997 (5). However, epidemiological data relating to spinal cord injury attributed to incidents in competitive swimming or formal training is scarce, and it is assumed that these injuries generally occur among recreational rather than competitive swimmers. Only two reports were found which made reference to competitive

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swimming. In South Africa, no diving injuries have been attributed to formal training or competition (14) while in Australia, only two incidents have been reported (11). Recently, Gehlsen and Wingfield (6) reported that, between the years of 1976 and 1984, there were 25 spinal cord injuries in the USA which resulted from competitive starting block entries. However, they did not distinguish whether competitive or recreational swimmers performed these entries.

A number of studies have investigated competitive dive starts. While the emphasis has been on the role of the start in improving race performance, maximum depth of dives has been reported in some. A comparison of the flat, track and scoop start techniques from standard 0.75 m starting blocks conducted at Indiana University (4), revealed that the average depth reached by males for the scoop start (1.22 m ± 0.33) exceeded that of the flat (0.74 m ± 0.16) and track (0.70 m ± 0.14) techniques for 10 - 17 year old swimmers. For the female participants, depths of 0.99 m (± 0.21), 0.68 m (± 0.12) and 0.70 m (± 0.11) were recorded for the scoop, flat and track starts, respectively. The water depth in this study was 4.88 m (16 ft). High speed rotary video-cameras were used to make above and below water recordings of two trials for each of the three dive types. Gridlines on the side wall of the pool were used to determine depth, horizontal distance and angle of entry. A performance measure of time-to-9.14 m (10 yd) demonstrated that the scoop start which, due to its greater depth, is potentially more dangerous, was not superior to the flat and track starts. Counsilman et al. (4) recommended that even skilled swimmers should not perform the scoop start in water less than 1.22 m deep.

A second study compared the scoop and flat starts, and also found the depth reached by both male and female competitive swimmers was greater for the scoop than the flat start (16). Again, starts were performed from 0.75 m starting blocks, this time into 3.8 m deep water (12.5 ft). Two trials of both the scoop and flat starts were recorded, using 16 millimetre films at 100 frames per second. Analysis via frame-by-frame projection onto a Numonic digitiser enabled the measurement of maximum depth of the head; time to reach maximum depth and angle of entry of head, neck and torso. Men achieved average maximum depths of 0.68 m for the flat start and 0.78 m for the scoop start, while women reached 0.52 m and 0.75 m for the flat and scoop starts, respectively. Welch and Owens (16) recommended a minimum depth of 1.37 m for skilled collegiate swimmers. They also recommended, without any supporting evidence, that for non-skilled or recreational swimmers, starting blocks should be removed or made inoperable if the water depth is less than 3.05 m.

Gehlsen and Wingfield (6) investigated the effect of starting block height and slope on flat and pike racing dives. Ten male and 10 female collegiate swimmers (NCAA Division 1), experienced in both types of dives, took part in the study. Analysis of above and below-water high speed video-recordings of the dives allowed comparison of entry centre of gravity displacement; entry centre of gravity angle; entry centre of gravity velocity; underwater centre of gravity displacement; centre of gravity velocity; angle of head, trunk and centre of gravity; and head depth. They found that all dives were of sufficient velocity to result in catastrophic spinal cord injury should impact with the bottom of the pool occur. They also recognised the value of good technique, implying that it contributed to the fact that none of the swimmers reached a depth of 1.4 m. Based on the depths attained by participants in their study, Gehlsen and Wingfield recommended a depth greater than 1.4 m for experienced competitive swimmers (6).

A study investigating the diving performances of 95 recreational swimmers found that the average depth reached for dives performed from a 0.75 m starting block was 0.64 m (± 0.27) when depth was measured at the site of the external auditory meatus (3). Participants in the study performed the dive technique of their choice. They wore swimming caps which were marked at the external auditory meatus and a mark was made on the arm in line with the external auditory meatus when the arms were extended beyond the head as they are in the usual diving position. The external auditory meatus was chosen as the site of measurement as pilot testing showed that this landmark could be most clearly distinguished on the video-recordings of dives and because it represents the centre of mass of the head. Other studies have not described the anatomical landmark which was used for measuring maximum depth (4, 16). Gehlsen and Wingfield (6) recorded depth measurements from a light emitted from a flashlight bulb attached to the top of the head. However, assuming the measurement was made at the deepest point reached, the study of recreational swimmers could have underestimated depth by approximately 0.15 m, as the external auditory meatus is about this distance shallower than the deepest point of the head. The addition of 0.15 m to the average dive depth takes the recreational swimmers to 0.79 m at the forehead (3). This is approximately the same depth as the scoop dives of the Welch and Owens study which were recorded at 0.78 m and 0.75 m for males and females, respectively (16).

Recreational swimmers, identified from an earlier study to be of low diving skill level, took part in a diving skills intervention program designed to improve their diving skills and safety (2). The program consisted of seven 10-minute skills sessions, which emphasised gliding and steering skills, and stressed the importance of keeping hands locked together and maintaining the arms in an extended position beyond the head until after reaching maximum depth. In this position, the hands and arms offer protection to the head and neck against impact. For this group, the mean depth of dive from a 0.75 m starting block decreased from 0.76 m (measured at the external auditory meatus) before intervention to 0.52 m (± 0.14) after. A follow-up evaluation of diving skill took place eight months later in which the mean depth of the block dive was recorded at 0.55 m (± 0.20) (1). These findings indicate that a relatively small amount of intervention can render diving skills of recreational swimmers to be safer. The mean depth after intervention was about the same depth as found for competitive swimmers (4, 16). The skill improvements were maintained for an eight-month period without any further intervention.

As FINA requires a minimum depth of 1.2 m for dives from standard starting blocks, many public pool managers have removed starting blocks from pools of less than this depth and competitive swimmers are prevented from practicing dive starts, possibly adversely affecting race preparation. It has been demonstrated that recreational standard swimmers are able to perform shallow, safer dives after participating in an intervention program of only 70 minutes duration (2). It follows logically that the emphasis placed on refining diving skills in competitive swimming squads will result in a superior diving skill level in the competitive swimming population.

The authors deemed it valuable to determine the depths achieved in competitive dive starts by elite junior swimmers and whether the depth varied with a change in water depth. The dive starts of a group of competitive swimmers were examined in order to produce data of typical dive depths. This study is comprised of two parts - Part one established the depths achieved in competitive dives from starting blocks while Part two compared depths when dives were performed into deep (2 m) or shallow (1.2 m) water. The maximum depth reached was used as the criterion measure and this was analysed from video-recordings of dives.

Methods

Part One

Thirty male and twenty-four female elite junior swimmers (mean age 15.3 ± 2.4 years) performed their preferred competitive dive start following normal competition procedures, from standard starting block height (0.75 m) into 2 m deep water. No instructions were given to swimmers other than those of a regular competition. Above and below water video-recordings were made of the dives, using Panasonic S-VHS MS4 and MS5 cameras at a sample rate of 50 Hz. Above water recordings were made using an MS4 camera positioned 2.3 m from the end of the pool. An MS5 camera was used for underwater recordings, where picture quality was paramount. It was positioned 3.5 m from the end of the pool in an underwater viewing window. Cameras were positioned 11.5 m from the dives to ensure the field of view encompassed the entire diving movement. Figure 1a illustrates the position of cameras.

Prior to commencement of the dives, video recordings were made of above and below water reference structures placed in the plane of movement and which encompassed the entire field of view. The reference structures were removed prior to dive performance. In order to control for systematic distortion introduced by the use of wide angle setting of the video zoom lens, spatial coordinates obtained from anatomical landmarks of subjects were related specifically to the section of the reference structure positioned in the same space as the landmark at that time. The video image was manually digitised from an orthogonal projection of the image onto a 1.8 m x 1.2 m flat white screen via an ELECTROBOARD LITEPRO 550LS data projector. Swimmers wore a cap with a marker at the external auditory meatus. Another mark was made on the upper arm in line with the external auditory meatus when the arms were extended above the head, as is the case with a dive entry. The greater trochanter of the femur was also marked. The cap and arm markings were used for subsequent underwater measurements, while the cap and trochanteric markers enabled the determination of angle of entry. Maximum depth, distance at maximum depth, velocity at maximum depth, angle of entry and flight distance were measured from the video-recording of the dives, and maximum and minimum values, along with means and standard deviations, were determined (2, 3).

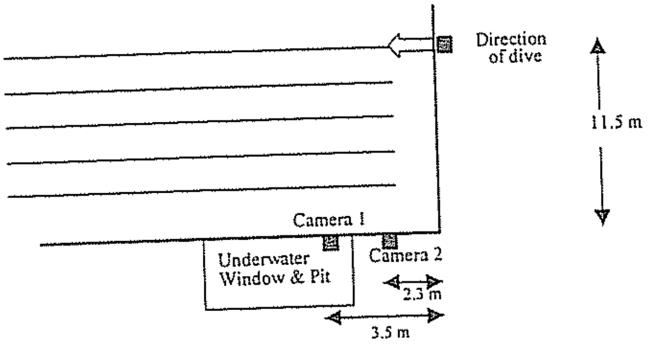

Figure 1a: Schematic diagram of equipment set-up in 2 m water depth

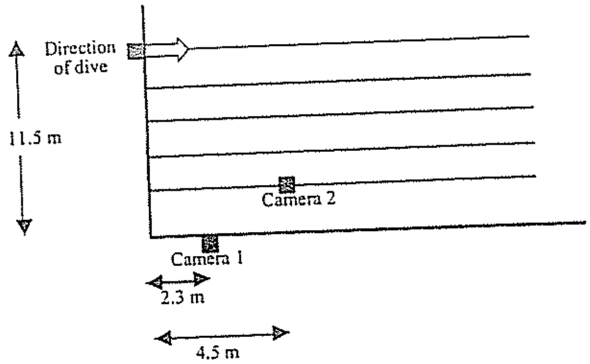

Figure 1b: Schematic diagram of equipment set-up in 1.2 m deep water

Part Two

Following completion of part one, thirty-six of the participants also performed a dive, following normal competition procedures and without instruction to remain shallow, from standard starting blocks (height 0.75 m) into water of 1.2 m depth. Swimmers had already performed a warm-up swim in the pool, commencing at the shallow end (1.2 m) and were therefore familiar with the depth. Video recordings were made of the dives using the same procedures as in Part one, except for the placement of the underwater camera. As there was no underwater viewing window at the shallow end of the pool, a Panasonic S-VHS MS1 camera was placed in an underwater housing and positioned 4.5 m from the end of the pool (see Figure 1b). This ensured the entire diving motion would be recorded.

Maximum and minimum values, and means and standard deviations for the measures of maximum depth, distance at maximum depth, velocity at maximum depth, angle of entry and flight distance were recorded. Paired t-tests were used to determine whether any significant differences were evident between the diving strategies employed when diving into deep or shallow water. Given the low number of independent variables, Bonferoni corrections were not included to reduce the chance of Type II errors. The alpha level was selected at 0.01 to adjust for the multiple t-tests that were performed.

Findings

Part One

The means, standard deviations and ranges for each of the parameters measured for the 54 participants in Part one are included in Table 1. The measure of maximum depth has been increased by 0.15 m, to account for the difference between measurement at the external auditory meatus and actual maximum depth.

Table 1: Means, standard deviations and ranges for the five measured parameters. (N = 54)

Variable			
Maximum depth (m)	Mean (± SD)	0.88	± 0.15
	Min	0.50	
	Max	1.28	
Maximum distance to maximum depth(m)	Mean (± SD)	4.93	± 0.56
	Min	3.93	
	Max	6.33	
Velocity at maximum depth (m/s)	Mean (± SD)	2.35	± 0.46
	Min	1.13	
	Max	3.00	
Angle of entry (degrees)	Mean (± SD)	42	± 7
	Min	26	
	Max	57	
Flight distance (m)	Mean (± SD)	3.01	± 0.35
	Min	2.50	
	Max	4.10	

NB: Depth measures for this study were made at the level of the external auditory meatus. For comparison with other studies which reported maximum depth, 0.15 m was added to the reported values as it was considered this represented the underestimation of depth of the deepest point of the head.

Part Two

Table 2 lists the means, standard deviations and ranges for each of the measured variables for the deep and shallow water dives. The results of paired t-tests for each variable are shown in Table 3. Maximum depth was the only variable to demonstrate a significant difference between the deep (0.88 m ± 0.17) and shallow (0.79 m ± 0.13) water dives, indicating that the competitive swimmers performed dives which were shallower by an average of 0.09 m when they dived into water of 1.2 m rather than 2 m depth.

Table 2: Means, standard deviations and ranges for the two dive conditions (2 m and 1.2 m) for the five measured parameters. (N = 36)

Variable		2 m water depth		1.2 m water depth	
Maximum depth (m)	Mean	0.88	± 0.17	0.79	± 0.13
	Min	0.63		0.58	
	Max	1.38		1.08	
Maximum distance to maximum depth (m)	Mean	5.01	± 0.61	4.72	± 0.62
	Min	3.93		3.76	
	Max	6.33		6.30	
Velocity at maximum depth (m/s)	Mean	2.47	± 0.36	2.51	± 0.47
	Min	1.75		1.75	
	Max	3.00		3.63	
Angle of entry (degrees)	Mean	41	± 6	42	± 6
	Min	30		32	
	Max	53		58	
Flight distance (m)	Mean	3.02	± 0.32	3.03	± 0.30
	Min	2.53		2.38	
	Max	3.75		3.68	

NB: Depths in this table have been increased by 0.15 m from the depth measured at the external auditory meatus to adjust for the underestimation of the deepest point of the head.

Table 3: Paired t-test results

Variable	df	t-value	p-value (sig)
Maximum Depth	35	5.892	0.000*
Distance at Maximum Depth	35	2.401	0.022
Velocity at Maximum Depth	35	-0.479	0.635
Entry Angle	35	-1.871	0.070
Flight Distance	35	-0.593	0.557

* denotes significance at $\alpha<0.01$

Discussion

The average maximum depth reached from dives performed by 54 elite junior competitive swimmers using their preferred dive start technique from starting blocks into 2 m of water was 0.88 m (± 0.15). This value includes an adjustment to depth by 0.15 m to account for the difference between the external auditory meatus, the landmark used for depth measurement, and the deepest part of the head. This compares with average depths of 0.70 to 1.22 m, depending on the type of dive, for a group of competitive swimmers aged 10 - 17 years (4), and 0.52 to 0.78 m for collegiate swimmers (16). The investigations by Counsilman et al. (4) and Welch and Owens (16) found that shallower dives were recorded for track and flat starts while greater depths were achieved for scoop dives. Table 4 lists the average maximum depths of dive entries from starting blocks as reported in the literature.

Table 4: Average maximum depth of dive entries from starting blocks (0.75 m)

Study	Gender	Type of Dive	Maximum Depth (m) (± SD)	
Counsilman et al. (4)	Male N = 55	Scoop	1.22	± 0.33
		Flat	0.74	± 0.16
		Track	0.70	± 0.14
	Female N = 66	Scoop	0.99	± 0.21
		Flat	0.68	± 0.12
		Track	0.70	± 0.11
Welch & Owens (11)	Male N = 18	Pike	0.78	
		Conventional	0.68	
	Female N = 12	Pike	0.75	
		Conventional	0.52	
Blitvich et al.(3)	Mixed N = 95	Participant Choice	0.79#	± 0.27
Blitvich et al.(2) Pre-Intervention	Mixed N = 34	Participant Choice	0.91#	± 0.26
Post Intervention		Participant Choice	0.67#	± 0.14
Current Study 2 m Water Depth	Mixed N = 36	Participant Choice	0.88#	± 0.17
1.2 m Water Depth		Participant Choice	0.79#	± 0.13

Depth measures for these studies were made at the level of the external auditory meatus. For comparison with other studies which reported maximum depth, 0.15 m was added to the reported values as it was considered this represented the underestimation of depth of the deepest point of the head.

Part two of this study allowed a comparison of the typical competition dive starts of participants when performed in deep (2 m) and shallow (1.2 m) water. The mean depth of dives was significantly reduced in the shallow water (p= .000). The competitive swimmers, aware of the depth reduction to 1.2 m, apparently automatically adjusted the depth of their dives to the shallower water but without significant differences in any other parameters. It should be noted that there was no significant change in velocity, indicating to coaches that the shallower dives did not result in a performance disadvantage.

The mean flight distances in this study were 3.02 m (± 0.32) and 3.03 m (± 0.30) for 2 m and 1.2m deep water, respectively. A slightly younger group of swimmers (mean age 14.8 years) recorded a mean flight distance of 2.91 m ± 0.4 (12). College aged males recorded a mean flight distance of 3.91 m (9), and Olympic swimmers were reported to reach 3.66 m, 3.93 m and 3.65 m for the whip (or scoop), grab and swing starts, respectively (18). As swimmers mature and their height increases, flight distance is expected to increase.

Only one other study was found which used the same method to measure angle of entry, which was using a line from the head to the hip when the head entered the water (12). It reported an entry angle of 43°, very similar to the values of 41° (in 2 m deep water) and 42° (in 1.2 m deep water) recorded in this study. Hobbie (7) calculated entry angle when hands first entered the water, using a line from the shoulder to the hip. An entry angle of 29.3° was reported. Other studies (4, 9, 16) found entry angles of 29° to 49° but did not detail their method of measurement. Lesser angles were recorded for flat and track starts than for pike starts.

The dive entries examined by Counsilman et al. (4) took place in a pool 4.88 m deep, while the water depth for dives studied by Welch and Owens (16) was 3.8 m. It is assumed participants in these studies were aware of the depth of the pool and as such may not have considered there was any need to keep their dives shallow. It is possible that the same swimmers would have performed shallower dives if the pool depth had been less.

When investigating diving safety, consideration must be made of the range as well as average depths because the dives of extreme depth have the greatest risk of spinal injury. The average depth recorded in shallow water was 0.09 m less than in deeper water, but the maximum depth was 0.3 m less in shallow water. The seven swimmers who reached a depth of 1 m or greater when diving into water of 2 m depth showed a greater decrease in dive depth than average when diving into the shallower depth. Descriptive statistics for these seven swimmers recorded an average depth of 1.14 m when diving into 2 m deep water, while the average depth they recorded when performing a dive into 1.2 m of water was 0.96 m, which is 0.18 m shallower. This decrease is twice that of the group average. It appears that the competitive swimmers are able to adjust for water depth changes. Nonetheless, the margin for error is small for these seven swimmers and future studies should obtain film from actual competition relays where swimmers, in a highly excited state, are distracted by the stress of competition.

Stone (15) calculated that an impact velocity of 0.61 m/s is sufficient to dislocate cervical vertebra, and an increase in velocity to 1.22 m/s is enough to crush cervical vertebra. The lowest velocity of the head at maximum depth recorded in this study was 1.75 m/s, indicating that every dive had the potential to result in a catastrophic injury should impact occur with the bottom of the pool. This fact clearly indicates the vital importance of the need to emphasise safety of dive starts in competitive swimming.

Applications

To enable competitive swimmers to maximise performance, dive starts need to be fast as well as safe. Preventing swimmers from practicing starts decreases both the potential speed of the start and its safety. This study demonstrates that competitive swimmers are able to adjust the depth of their dives when diving into shallower water, even without instruction to do so. It is of interest that there was no evidence of a sacrifice in speed during the shallower dives. It becomes clear then, when coaches are examining the depth of swimmers' dives, pool depth is an important consideration. A swimmer's common sense and skill enables safe dives to be performed. The findings of this study suggest:

1. The FINA minimum depth of 1.2 m for dive starts from standard (0.75 m) starting blocks (17) appears safe for use by skilled competitive swimmers.
2. Diving skills instruction should be provided for swimmers prior to performing dives in water of 1.2 m depth (16). Initially, instruction should occur in deep water to enable swimmers to refine their diving skills. As skills improve, coaches should provide opportunities for practicing dive starts in 1.2 m of water. This should happen before swimmers are required to compete using racing starts in this depth of water. Such instruction does not need to be extensive. A total of 70 minutes of appropriate instruction was sufficient for recreational swimmers to achieve a safe diving depth (2). It is likely that even less time would be required for competitive swimmers.
3. Coaches should make sure to draw the attention of swimmers to the depths when visiting competition venues. New swimmers to the home training venue should be similarly alerted. Automatic adjustment of dive depth is then likely to be facilitated.
4. Once swimmers have developed more refined diving skills, coaches should provide opportunities for practicing dive starts in 1.2 m of water. Ideally, this should happen before swimmers are required to perform actual racing dive starts in this depth of water, to allow them to practice diving into shallower water without the distraction of competition. Swimmers should be able to further refine their diving skills in training sessions.
5. Pending research evidence to the contrary, there is no indication that shallower dives are any slower than deeper dives and coaches should recommend that their swimmers perform the safer, slightly shallower techniques.
6. Further research should be conducted using methodology similar to that of the present study, but with the inclusion of an additional dive in both deep and shallow water. These additional dives should be conducted after the first dives have been completed and, for these dives, swimmers should be requested to remain shallow. A performance indicator, such as time to 10 m, should be included as a criterion measure. This will assist in answering the question as to whether swimmers can remain shallow without performance detriment. It will also help to determine whether the depth required for training and practice of competitive swimming starts is greater or lesser than the current minimum FINA depth of 1.2 m.

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Note

In order to narrow the focus of the In-Print bibliography, we have eliminated some articles that do not contain a significant scientific or research emphasis. This includes the entire Administration, Biography, Facilities, and Sports Law sections plus several articles from the Coaching, General, and Teaching sections. Readers who have a special interest in these areas may obtain a complete listing from the editor of the JSR.

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"Training using the stroke frequency-velocity relationship to combine biomechanical and metabolic paradigms"

1. Phase 1 of the training program was referred to as the " ________ " phase while Phase 2 was referred to as the "________________".
2. At any given swim velocity, the outcome of the training program was to ______ the metabolic cost, ______________ the stroke frequency and ______________ the distance per stroke.
3. The improvement in swim performance was observed to be __________ % over the four years of observation. This was greater than the improvements the authors cite from the available literature which was ________________%.

"Body temperature homeostasis during a 40 km open water swim"

1. During water immersion the convective and conductive heat transfer is about ______ times greater than for in air at the same temperature.
2. Three variables which act in concert to determine core temperature are __________, ______________, and ______________.
3. The maximal allowable distance between the signal transmitters and the temperature receivers is about ______________ meters.

"Peak blood lactate and accumulated oxygen deficit as indices of freestyle swimming performance in trained adult female swimmers"

1. The measures of LA_{peak} in the present study accounted for only ______% of the variance in 50 yard freestyle swim time thus making it of questionable use as an index of the anaerobic contribution.
2. Neither of the two independent measures of peak post-exercise blood lactate were found to be predictive of the ____________swimming performance.
3. Based upon the present study, it *is*, or *is not* recommended that measures of LA_{peak} or AOD be used as predictors of freestyle swimming performance?

"Dive depth and water depth in competitive swim starts"

1. Between the years 1976 and 1984, how many spinal cord injuries were reported as a result of competitive starting block entries in the United States?
2. The observed mean start flight distances in the study were approximately _____ meters or ________ feet.
3. The lowest velocity of the head at the maximum depth recorded was ______ ms-1 which is greater than the estimated velocity of _________ms-1 considered to be enough to crush the cervical vertebra. This suggests that every dive has the potential to cause a catastrophic injury, should impact occur.

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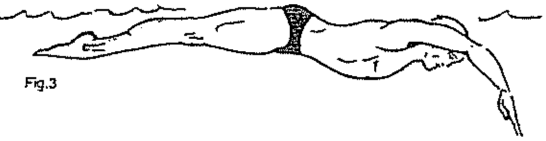
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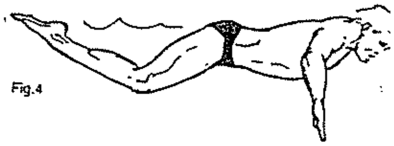
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