Developing a Strength and Conditioning Technical Framework: An Example From a Canoe Slalom National Performance Program

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ABSTRACT

Canoe slalom requires technical ability, well-developed energetics, a high level of maximum force production, and range of movement to perform a variety of complex paddle stokes, while maneuvering through a challenging whitewater course. The strength and conditioning (S&C) coach should provide strategic direction across a network or department including S&C coaches working toward identified outcomes and measures. S&C coaches should collaborate with a multidisciplinary support team (i.e., sport coaches, physiotherapists, physiologists, etc.) to develop a technical framework. The technical framework may allow for development of training strategies that provide a clear breakdown of the outcomes, adaptations, exercises, and testing methods. The current article articulates this process related to a canoe slalom national performance program.

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INTRODUCTION

Effective leadership of any strength and conditioning (S&C) program requires practitioners to demonstrate how the development of key biomotor qualities may be relevant for the respective sport, by providing an evidence-based rationale. Furthermore, the S&C program should have defined objectives that are strategically aligned with the goals of the training program. This may be achieved through the development of a technical framework, which may assist in decision making in regard to programming by outlining the physiological demands of the sport and the biomotor qualities contributing toward improving sports performance. In order for a technical framework to be developed, S&C coaches must develop a thorough understanding of the sport. When starting work in a new sport, practitioners often are required to develop a program within a short period and without any previous knowledge of the sport, posing a potential challenge. Therefore, it is important to have a clear process for deconstructing sports performance.

The aim of the current article is to elaborate a process that may be used to conduct an in-depth needs analysis to establish potential physical determinants of performance and build a technical framework. This process requires S&C coaches to use their understanding of functional anatomy, biomechanics, and physiology, to establish its kinetic and kinematic demands. In addition, it investigates key injuries within a sport and associated risk factors. Because of the complexity of this task and the breadth of expertise required, it is important that practitioners work collaboratively and use the expertise of members of the multidisciplinary team (MDT) (i.e., technical coaches, physiotherapists, physiologists, etc) to further their understanding of key areas and enhance the technical framework. Furthermore, collaboration with the MDT may also ensure that S&C program is strategically aligned with the goals of

KEY WORDS:
technical framework; needs analysis; canoe slalom; training strategies

the sport training program. The development of a technical framework may ultimately lead to the formation of tangible training strategies for the sport, which are aligned with the objectives of the S&C program and sport.

The current article uses the primary author's experience of leading a national canoe slalom performance program to demonstrate the process of building an S&C technical framework. Although canoe slalom has been used as an example in the current article, carryover to other sports may be possible. Because of the complex nature of canoe slalom, quantifying the physical demands of canoe slalom is challenging. There is currently no clear consensus as to what the primary physiological factors leading to success in the sport are (2). Therefore, because of the limited useful scientific research in canoe slalom, a number of resources were used within this process. This included empirical evidence from related sports, the author's understanding of functional anatomy, physiology, and biomechanics, as well as collaboration with the MDT.

NEEDS ANALYSIS

Conducting a thorough needs analysis is crucial for developing an S&C technical framework. This may consist of 2 key areas: (a) sport demands and (b) high-risk injury areas (Figure 1). First, a needs analysis of the sport demands may allow S&C coaches to understand the make-up of the sport, rules and regulations, key sporting actions, as well as associated kinetic and kinematic demands, and, in addition, understanding the energy system requirements of the sport. From the author's experience, a review of published literature is an appropriate starting point. Other members of the MDT may also be a good source of knowledge and allow opportunities for integrated practice. For example, the sports coach may provide an insight into the technical demands, the physiologist may have an in-depth understanding of the energetic requirements, and the physiotherapist may help develop an understanding of mechanisms underpinning key sites of injury.

There is a scarcity of useful research in canoe slalom that is practically applicable. Therefore, the information collected in the needs analysis–to understand the sport demands–was primarily through the latter source and literature from related sports such as flat water sprint canoeing. For instance, research on the kinetic demands of sprint canoeing (i.e., the mechanics of force generation and transfer of force from blade to boat) may be applicable to canoe slalom. When using literature from other sports to make inferences, it is vital for S&C coaches to maintain scientific rigor (understanding of similarities and differences of underpinning anatomy, physiology, and biomechanics). A needs analysis of high-risk injury areas may identify key sites of injury occurrence for both the sport and the specific population. This may be performed through initially conducting a literature review of injury trends within the sport, followed by collection of in-house injury surveillance data to identify potential injury trends within the specific athlete population. To understand the risk factors and associated mechanisms for key sites of injury, it is crucial to develop an in-depth understanding of the functional anatomy of these sites and associated physiology. Collaborations with physiotherapy colleagues may be crucial for this process to be conducted effectively. For the purpose of this article, only injury trends identified from the literature will be discussed.

SPORT OVERVIEW

The sport of canoe slalom involves athletes paddling their boat down

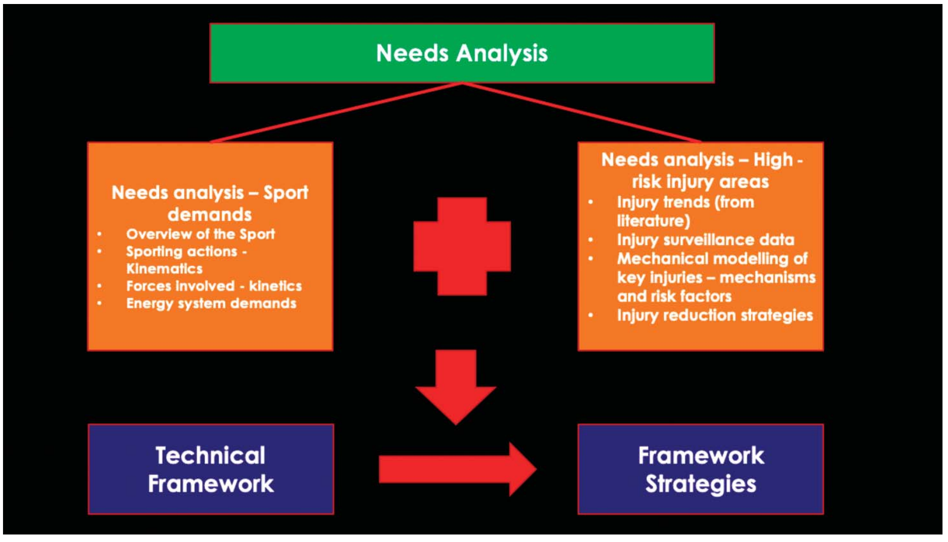

Figure 1. Representation of key areas of a needs analysis, resulting in the development of a technical framework and training strategies.

a whitewater course, through a series of gates. A course can have a maximum of 25 gates (with at least 6 upstream gates) and a maximum length of 300 m. The gates are poles suspended over the water and are colored red or green. The red poles indicate a gate, which must be negotiated upstream, whereas the green gates must be negotiated in a downstream direction. Courses may be either natural or artificial. Each course is designed differently, and the set-up of gates is changed for each race.

The aim of canoe slalom is to cross the finish line in the shortest time possible. To successfully complete a run, athletes must pass through all gates without any part of their body, boat, or paddle touching the poles. A 50-second penalty may be given for incorrect navigation of a gate and a 2-second penalty for contact with a gate (15). Each race consists of 2 runs, with fastest time from the 2 runs used to determine the placing of the athlete within the competition. Olympic canoe slalom consists of 2 disciplines: the single canoe (C1) and the single kayak (K1) events. In the C1 (Figure 2), athletes use a single-bladed paddle and are strapped into a kneeling position with knees flexed and heels tucked under the body. By contrast, the K1 (Figure 2) involves athletes paddling with a double-bladed paddle and seated with legs placed in front of them. The hips are externally rotated; the knees slightly flexed, so they can be placed against the side of the kayak; the feet are placed firmly against a footplate.

An elite canoe slalom race typically lasts between 90 and 110 seconds, dependent on the course design, course length, and boat class (23). The longer the course, the greater the disparity between canoe and kayak times. Kayak times are faster than canoe times for 2 primary reasons: (a) the boat demonstrates a faster hull speed and (b) the double-bladed paddle allows for a faster turnover speed and eliminating the need for correction strokes on the offside (C1 paddler in Figure 2) to keep the boat on course (1). Despite this, it has been shown that C1 times are not significantly slower than K1 times (10).

SPORTING ACTIONS AND FORCES INVOLVED (PADDLE MECHANICS–KINETIC AND KINEMATIC DEMANDS)

To move a canoe or kayak forward, a paddler must generate forward propulsion to overcome drag forces acting on the boat. This is achieved by generation and efficient transfer of force from the paddle, through the kinetic chain, and to the boat, through the seat and foot plate (only applicable in the kayak) (1). Paddlers are required to apply force against the water through the paddle blade, resulting in forward propulsion (1). According to Newton's third law of motion (to every action there is an equal and opposite reaction), to move a boat forward in the water, paddlers need to use the paddle to apply a backward force to it. However, the "reaction force" is not equal and opposite to the "action force" because some force is used to induce movement in the water (due to water not being a solid element, it moves when force is applied) rather than generate forward propulsion. To maximize force generation in water, paddlers much have "propulsive efficiency," which is the ability to generate a high reaction force for a given action force (3).

Canoe slalom paddlers perform a variety of paddle strokes during the course of a race. For the purpose of S&C programming, paddle strokes may be divided into 2 broad categories. They are forward propulsive and rudder strokes, with forward propulsive strokes being the predominant stroke performed across a race. Rudder strokes are used to turn the boat and consist of 3 major variations (i.e., bow rudder, reverse, and sweep stroke). A single stroke is defined from the start of the catch phase (point of entry of the blade in the water) to the start of the next catch phase on the opposite side of the boat (on the same side in the case of C1), including the time the blade is in the water. The time the blade spends in the water subsequent to initial entry is defined as the pull phase. The recovery phase is the time between catch phases (22).

Because of the unpredictable nature of whitewater paddling, these strokes can be performed in a multitude of angles, taking the glenohumeral joint (GHJ) through a complex combination of movements, coupled with movement of the spine. The underhand (side of the paddle, i.e., immersed in water) (Figure 2) may produce the

Figure 2. A C1 (single canoe) (left) and K1 (single kayak) (right) paddler performing a forward propulsive stroke, with the C1 paddler performing the stroke on the offside (blade in the water on the opposite side of the boat).

majority of the force. Therefore, the focus in this section will be to examine the kinematics of the shoulder on the side of the underhand. In forward propulsive strokes, the primary action of the GHJ on the side of the underhand is extension, suggesting that the latissimus dorsi and posterior deltoid play a critical role in force generation (13), along with other muscles of the upper back. Depending on the boat position and stroke variation, GHJ extension may be accompanied with internal rotation and adduction. The pectoralis major and the anterior deltoid may act eccentrically to stabilize the shoulder joint, playing a key role during forward propulsive strokes. The converse muscle action may occur during rudder strokes. The less frequently performed rudder strokes involves GHJ flexion on the side of the underhand as well as horizontal adduction, depending on the stroke variation used. The bow rudder involves the GHJ on the side of the overhand performing close to end range flexion and external rotation.

The spine undergoes a complex combination of movements in canoe slalom. Rotation of the spine occurs during each stroke, often coupled with flexion, in addition to lateral flexion also being performed, depending on stroke variation and boat position. For instance, a degree of lateral flexion may be performed on the side of the underhand during the bow rudder stroke. The trunk rotates to the side of the underhand during the catch and through the pull phase. Trunk rotation and GHJ extension must occur simultaneously to maximize force transfer across the kinetic chain as well as ensuring optimal summation of forces from the trunk and GHJ extensors (31). Based on the above examination of the kinematics and kinetic demands of canoe slalom, it is clear that paddle mechanics involves a complexity of movement at the GHJ and spine. And to ensure optimal physical preparation, paddlers may require high levels of upper extremity force production capability, appropriate range of movement (ROM), and the ability to transfer force across the length of the kinetic chain.

ANTHROPOMETRY

Despite any supporting empirical evidence, it is a commonly held belief among athletes and coaches in canoe slalom that increases in muscle cross-sectional area (CSA) in the lower extremity may be detrimental to performance due to increased mass in the front of the boat (particularly in the kayak). A study conducted to demonstrate the morphological characteristics of elite male (28.1 ± 5.2 years) and female (26.3 ± 4.8 years) canoe slalom paddlers (24) may provide useful information (Table) for S&C coaches, working with coaches and athletes that are concerned about increases in CSA. As canoe slalom is not a weight class sport, an increase in CSA as a result of long-term strength training (26) to develop *F*max may be beneficial for performance, provided that paddlers match the anthropometric profiles observed within an elite canoe slalom population (Table).

ENERGY SYSTEM DEMANDS

In a study on the bioenergetic demands of elite-level canoe slalom, it was shown that approximately 45–50% of the energy contribution comes from the aerobic system and 30–35% from the glycolytic system (33). Although not explicitly mentioned in the study, this may indicate that the remaining contribution is from the ATP-PC system. Speed profiling (attained from global positioning system data) has shown that the event is more intermittent in nature with periods of high speed (up to a velocity of approximately 4.5 $m \cdot s^{-1}$) (sections in which paddlers go downstream from one gate to the next) alternated with periods of reduced speed (as low as 0.5 $m \cdot s^{-1}$) (upstream sections) (33). Furthermore, it has been shown that whitewater is released from pumps on an artificial course at a speed of approximately 14 $m \cdot s^{-1}$(9), providing an indication of the high level of external force acting upon paddlers. During the higher velocity portions of the race, experienced paddlers may often use their ability to read the current and use the flow of whitewater to propel the boat down the course (33). It is during sections of relatively calmer water, typically around gates, that requires application of higher forces to generate forward propulsion as well as turning the boat through rudder strokes. Elite male kayak paddlers have been shown to attain a peak heart rate (177 ± 7 bpm) that is approximately 92% of their maximum heart rate and a peak blood lactate concentration (8.1 ± 1.6 mM) that is approximately 63% of maximum blood lactate values (33) during a canoe slalom race. It is possible that these peak heart rate and blood lactate values were observed during periods of high force generation. Therefore, well-developed aerobic system may allow for recovery between these high-intensity bouts through partial reoxidation (32). This may be crucial for athletes to effectively use their force generation capabilities to generate forward propulsion across a race. Most research on the energetic demands of canoe slalom (2,33) have been conducted on K1 paddlers. However, because of C1 times being nonsignificantly slower than K1 times (15), these findings may be applicable to the race demands of C1.

The primary determinants of aerobic energy production are maximal aerobic power ($\dot{V}O_2max$) and aerobic capacity (the maximal amount of work that can be performed at any given time) (20). Elite paddlers have been shown to have $\dot{V}O_2max$ values of approximately 48.7 ± 6.9 $ml \cdot min^{-1} \cdot kg^{-1}$ (attained from a kayak ergometer [Figure 5] $\dot{V}O_2max$ test) (33). A longitudinal study investigating the maximal aerobic power of Olympic and non-Olympic paddlers across 3 Olympic cycles showed no significant difference in $\dot{V}O_2max$ between groups (2). This may suggest that maximal aerobic power may not be a major determining factor for performance, once the required level has been reached and aerobic capacity may be of greater importance (as this may improve economy–cost of work that may be performed in a given period).

Table
Anthropometric profiles of elite canoe slalom paddlers (24)

	Body mass (kg)	Height (m)	Sum of 6 skinfolds (mm)	Chest girth (cm)	Flexed arm girth (cm)	Waist girth (cm)	Hip girth (cm)	Thigh girth (cm)	Calf girth (cm)
Males	72.5 ± 5.8	1.77 ± 0.07	35.5 ± 6.4	102.9	35.0 ± 1.5	80.2 ± 3.4	91.8 ± 3.3	53.5 ± 2.0	35.7 ± 1.3
Females	59.0 ± 4.4	1.68 ± 0.05	44.8 ± 9.8	91.0 ± 3.6	30.1 ± 1.0	69.9 ± 2.6	89.7 ± 2.7	52.9 ± 2.1	34.1 ± 1.2

For the inexperienced paddler who may lack technical expertise, the energetic demands of a race could differ, and it is possible that there may be a greater utilization of the glycolytic system due to the need to produce high forces for greater sections of the race. Rather than focusing on energy system development, it may be more appropriate for developmental paddlers to focus on the development of technical expertise, ROM, upper extremity force production, and the ability to transfer force across the kinetic chain. As technical expertise increases, athletes may naturally adopt the energetic profile of more experienced paddlers.

HIGH-RISK INJURY AREAS

Although direct traumatic injuries occur occasionally, most injuries in canoe slalom may occur due to the use of improper biomechanics or repeated overloading of the muscle tendon unit. The shoulder (11,18) and lumbar regions (18) have been observed as the most vulnerable and frequently injured structures. This may be due to the extreme ranges of movement that the GHJ and spine undergo, coupled with high forces that may be generated and act upon the body from external sources, that is, whitewater. It has been suggested that suboptimal shoulder performance in the form of poor quadrant posture, muscle imbalances, and improper motion may cause or perpetuate subacromial impingement syndrome, internal shoulder impingement, rotator cuff pathology, and several other shoulder pathologies (13). These may be related to sports-specific demands placed on the GHJ as described in the previous section.

The lumbar spine is exposed to a variety of forces during rotation. Rotation does not directly pose a risk to the lumbar spine. On the contrary, it has been shown to improve the resilience of intervertebral disks (IVDs) by improving fluid exchange and increasing nutrient turnover within the disk. However, if rotation is performed beyond the commonly achieved ROM, stress on the IVD occurs, damaging the annulus fibrosus section of the disk. The maximal available range of motion in the lumbar spine is believed to be approximately 5–7° (10). Once rotation occurs outside this safe zone (normal functional ROM, within which no there is no undue stress to connective tissue), facet joint compression occurs, and compressive forces increase (5). Paddlers often perform coupled rotation and flexion, which has been shown to have significant effects on disk and vertebral dynamics. For instance, it has been shown that the range of spinal rotation is reduced when the spine reaches close to end range flexion (4). Research in sweep rowing that also involves coupled rotation and flexion has shown compressive forces to reach up to 4.6× body mass (BM) (29). Therefore, supramaximal coupled flexion and rotation may lead to tensile stress on the annulus layers of the IVD and increase disk compression (27). Over time, this may result in chronic spinal injuries such as disk degeneration and spondylolysis as well as acute strains and sprains that may occur due to muscular damage (10). Based on the possible mechanisms behind shoulder and spinal injuries described above, it may be vital for athletes to have sufficient ROM and the ability of the surrounding trunk musculature to stabilize the respective joints.

TECHNICAL FRAMEWORK

Having developed an understanding of the sport, it is important to formulate S&C objectives for the sport that are aligned to the aims of the broader program. Collaboration with the sport coaches and the performance director (in the case of a national governing body) when developing these objectives may be important. In the current article, 4 objectives have been identified, with 3 key elements and 2 subelements that may allow these objectives to be achieved (Figure 3).

- *Contribute toward maximizing power output for the duration of the race:* As canoe slalom may be described as an

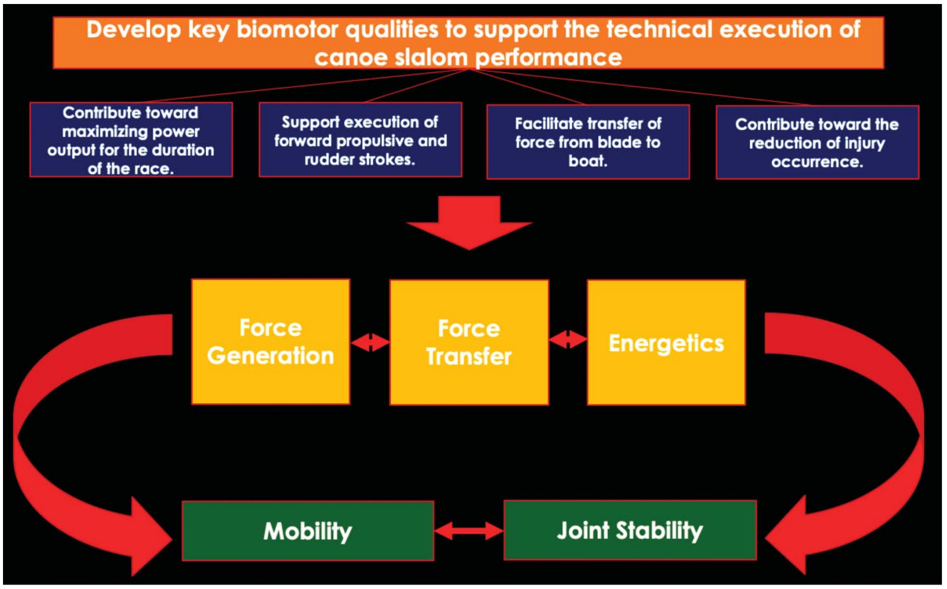

Figure 3. Schematic representation of the technical framework, illustrating how developing key biomotor qualities that are addressed within an S&C program may achieve S&C objectives and contribute toward sporting performance.

intermittent high-intensity event, a high *F*max may allow athletes to either produce the same force at a lower relative cost or a higher force through an increased stroke rate during periods requiring high force application.

- *Support the execution of forward propulsive and rudder strokes*: Because of the complex movement of the shoulder as well as the lumbar and thoracic spine during execution of paddle strokes, it is critical to have optimal ROM, joint stability, and force capabilities to not only support efficient technical execution but also minimize potential injury risk due to lack of physical preparedness.
- *Facilitate transfer of force from blade to boat:* It is vital for paddlers to be able to transfer force from distal sites of force generation to proximal sites of force application and vice versa. Any dissipation of force may potentially impact stroke efficiency.
- *Contribute toward the reduction of injury occurrence:* By developing strategies to physically prepare high-risk injury areas such as the lumbar spine and shoulder complex, the S&C program may contribute toward reducing the risk of injury occurrence.

Like many sports, canoe slalom is highly technical and by maximizing on water time, a significant performance impact may be made.

FRAMEWORK STRATEGIES

In order for the framework to be implemented, it is imperative to devise tangible training strategies for each element of the framework (Figure 4). Each strategy consists of an outcome, the physiological adaptation that is the primary driver in achieving the outcome, training applications that may allow for appropriate exercise selection for any given athlete and testing methods. It is important to note that there is a crossover between training applications for the different strategies listed below (i.e., certain training applications will contribute toward the attainment of multiple outcomes).

FORCE GENERATION

Force generation for forward propulsion occurs primarily from the upper extremity. Research in sprint canoeing has shown a correlation between upper-body pulling strength and start performance across 2, 5, and 10 m times as well as peak velocity (30). This suggests that in order for canoe slalom paddlers to maximize “propulsive efficiency” during sections of calmer water near gates, upper extremity force generation may be crucial. As the GHJ extensors and pectoralis major play a key role in force production as well as stabilization of the GHJ, vertical and horizontal pushing as well as pulling movements may be used to generate high forces during forward propulsive and rudder strokes, respectively. Dependent on the anthropometry of the athlete, training may target both neural and muscular adaptations.

FORCE TRANSFER

Movement of the lower extremity below the pelvis is limited, and as a result, the lower extremity may not contribute toward force generation. However, training the lower extremity plays a key role in the transfer of force from blade to boat due to being the point of contact between the seat and foot plate. To transfer force through the kinetic chain, minimizing any dissipation of force is critical, and stability at key anatomical sites (the pelvis, spine, scapula, and GHJ) is required to ensure effective force transmission across the kinetic chain through the fascial connections between gluteus maximus and

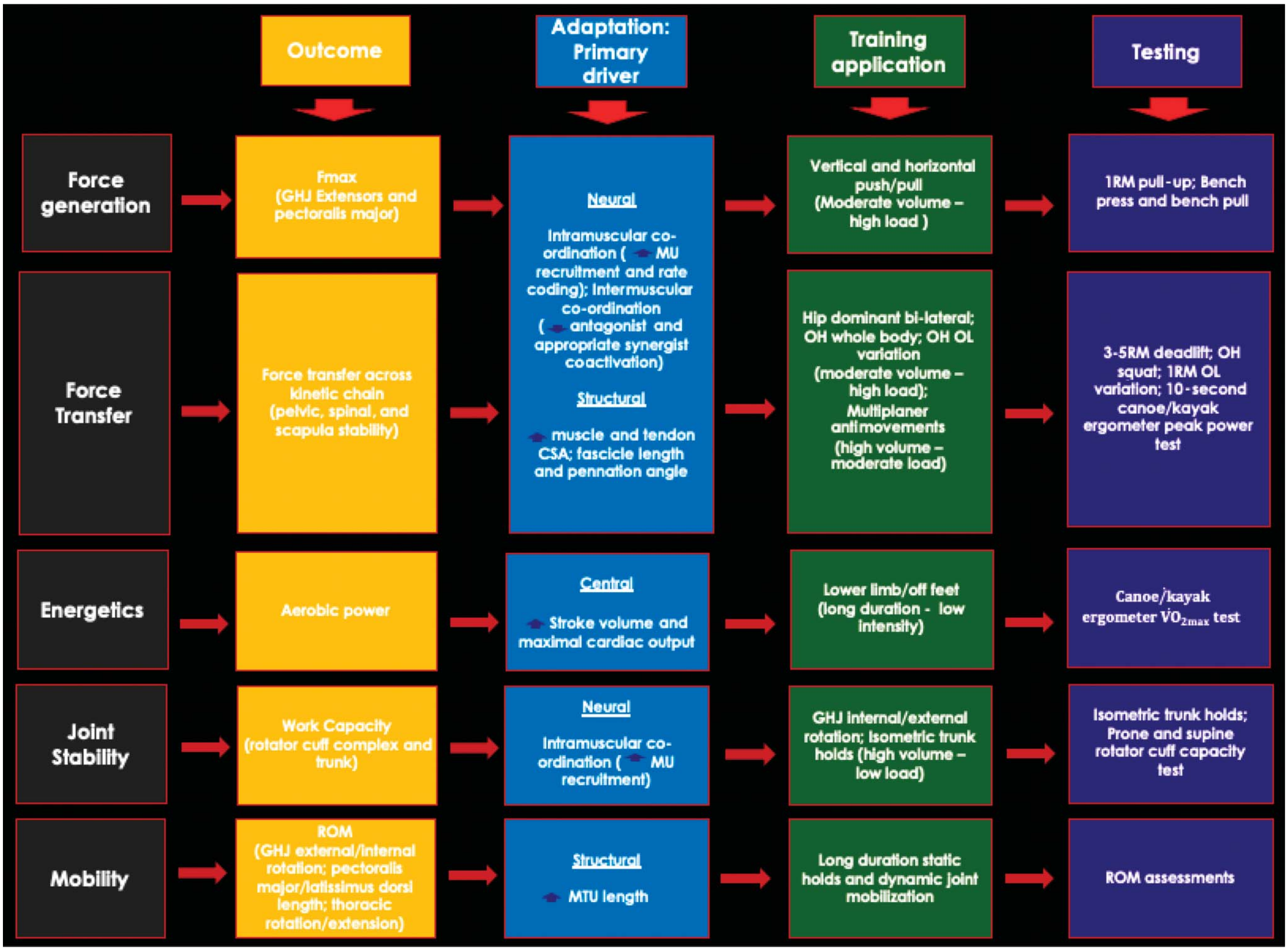

Figure 4. Strategies for implementation of each element of the technical framework (*F*max, maximum force; GHJ, glenohumeral joint; MU, motor unit; CSA, cross-sectional area; RM, repetition maximum; OH, overhead; OL, Olympic lift; ROM, range of movement; MTU, muscle tendon unit).

latissimus dorsi (14) during paddling. Poor joint stability down the kinetic chain may result in improper joint alignment further up the kinetic chain, affecting length–tension relationships of muscles acting across joints, which is critical for optimal force transfer. Within the context of this article, joint stability (with the exception of the scapula that may not be classified as a true joint) refers to the ability of both local and global muscles to work together to ensure joint congruency (25).

Suboptimal pelvic positioning may impact joint alignment of the spine, due to muscular connections between the pelvis and lumbar spine. As paddlers often paddle with coupled spinal flexion and rotation, this has ramifications for injury risk. Therefore, maintaining appropriate pelvic and subsequently a more neutral lumbar spine while paddling may contribute toward mitigating the risk of lumbar spine injuries. Similarly, a lack of thoracic extension may affect scapula stability as the scapula glides over the rib cage, which attaches to the thoracic spine (19). Dynamic stability of the scapula is vital for optimal scapulohumeral rhythm–due to the rotator cuff muscles that originate from the scapula and insert into the humerus–playing a key role in stabilizing the GHJ (congruency of the humeral head in the glenoid fossa). Scapulohumeral rhythm refers to scapular movement in relation to humeral movement. It is believed that one degree of scapula movement for every 2 degrees of humeral movement may allow for efficient scapulohumeral rhythm. This is achieved through force couples (co-contractions) of the primary scapula stabilizers (trapezius, rhomboids, and serratus anterior) (19). This is critical not only for force transfer but also for shoulder health because lack of stability in the GHJ may lead to shoulder pathology, as described previously (see –high-risk injury areas).

Bilateral hip dominant exercises such as an accentuated eccentric deadlift (Romanian deadlift performed during the eccentric phase followed by controlled lowering to the floor) may develop the ability of the athlete to use primarily posterior musculature across the kinetic chain to transfer force through the length of the body, while maintaining stability through the pelvis, spine, and scapula. As the outcome is to facilitate force transference rather than develop *F*max, a predicted 1RM accentuated eccentric deadlift (derived from a working 3RM) may be used rather than a 1RM. As maintaining joint alignment through optimal technical execution of the lift is vital for the assessment of joint stability under load. In a similar manner, an overhead whole-body exercise such as an overhead squat may allow athletes to also develop this ability, while bearing a load overhead, which requires optimal scapula upward rotation and GHJ external rotation. This may also allow for the development of strength of the psoas major and hip abductors as well as external rotators (gluteus medius and minimus) that play an important role in stabilizing the spine and pelvis, respectively (21). Vertical pushing and pulling movements may also help develop scapula stability because they train the scapula stabilizers to ensure the scapula moves through a full ROM. An overhead lift such as the snatch may be used to develop the athlete's ability to perform this function during a dynamic movement, further preparing paddlers for the demands of paddling. There is evidence to suggest that the major sagittal plane compound movements such as deadlifts, overhead squats, and snatch may be used to train the trunk (7), which is critical for transferring force across the kinetic chain and stabilizing the spine. However, supplementary trunk exercises may also be used to train the trunk (see section 5–joint stability).

Finally, it may be of benefit to demonstrate the transfer of *F*max toward paddling performance. Peak power measured from a 10-second canoe or kayak ergometer sprints (Figure 5) may be used to demonstrate a relationship between biomotor qualities developed within the S&C program (i.e., *F*max) and a sport-specific outcome measure (i.e., ergometer peak power). The development of upper extremity *F*max is a well-accepted part of canoe slalom training. However, training of the lower extremity is often lacking buy-in among coaches and athletes. Along with a clear rationale to justify the use of lower extremity strength training (as outlined above), the use of data showing correlations between strength measures and performance outcomes may strengthen the case (6). As the aim of the current article is to demonstrate the process of deconstructing sports performance to develop a technical framework, the statistical processes used to establish correlations between performance outcomes and biomotor qualities are beyond the scope of this article.

ENERGETICS

Adequate energy system development is required to allow for sustainability of force production for the duration of the race, with the aerobic energy system being the primary energy contributor (33). A combination of both central and peripheral factors may influence an athlete's maximum aerobic power and capacity. Central adaptations may play a dominant role in developing maximum aerobic power, and peripheral factors may play a greater role in developing aerobic capacity (20). To ensure maximal transfer to canoe slalom performance through peripheral adaptations in the upper extremity, it may be optimal for energy system development to be performed in a task-specific manner. As most canoe slalom training are performed at relatively high intensities, it is possible that central adaptations may not be optimally attained through on-water training. This is based upon the understanding that central adaptations may require a component of training to be of longer duration–lower intensity in nature (e.g., if an athlete's lactate threshold was at 75% of $\dot{V}O_2$max, the optimal intensity would be 70–75% of $\dot{V}O_2$max, performed as 4–9 minute intervals, with 1-minute rest in between intervals and with a total session time of approximately 40–60 minutes) (20). It is generally accepted that central factors play a dominant role in determining maximal aerobic power ($\dot{V}O_2$max) (20). In addition, it has been shown that improvements in $\dot{V}O_2$max are correlated with increases in maximum cardiac

Figure 5. A kayak (left) and canoe (right) ergometer.

output (central adaptation), and work capacity is correlated with increases in mitochondrial enzyme activity and muscle capillary density (8,12). On this basis, land-based conditioning may be used to supplement on water energy system development for paddlers that do not possess the required levels of aerobic power ($\dot{V}O_2$max assessed on a paddling ergometer [Figure 5]). A detailed description of on-water training for canoe slalom is beyond the scope of this article.

The aim of land-based conditioning is to target central adaptations, through non–task-specific modalities. Cardiovascular equipment such as stationary bikes may be suitable as this approach may be of benefit in regard to off-loading the upper extremity, which is heavily used during on-water training and S&C sessions. Bike-based conditioning has been shown to have a lower interference effect on adaptations from strength training, due to lower global energetic demands (32). Aerobic sessions may be best placed on separate days to strength training. However, if performed on the same day, strength training should be performed before aerobic training (9) and as close to 6 hours apart as possible (17). For athletes who may have already attained a $\dot{V}O_2$max that is reflective of elite-level paddlers or for whom force production may be a limitation, it may be of benefit to remove or limit land-based aerobic training to prioritize the development of *F*max. This is based on the rationale provided in the needs analysis that other elements (*F*max, force transfer, mobility, and joint stability) may be placed higher up the hierarchy of needs for contributing toward enhancing performance and reducing the risk of injury occurrence in canoe slalom paddlers.

MOBILITY

Adequate mobility across key sites in the kinetic chain is important to allow paddlers to attain optimal positions for performing paddle strokes. Internal and external rotation of the GHJ and thoracic rotation are critical for paddlers to achieve desired ranges of movement during paddling. In addition, a lack of internal and external rotation may be a risk factor for shoulder pathology, described previously (see–high-risk injury areas). Pectoralis major and latissimus dorsi length may also contribute toward GHJ external rotation due to both muscles inserting into the intertubercular groove of the humerus. Because of the limited ROM of the lumbar spine, insufficient thoracic rotation may have implications for injury risk of the lumbar spine as a result of the lumbar spine being forced outside of its normal ROM. As already mentioned, thoracic extension may impact scapula movement due to the positioning of the scapula on the rib cage, which attaches to the thoracic spine. ROM assessments may be conducted as part of physiotherapy screening. To increase the ROM of the areas highlighted above, long duration static stretching and dynamic joint mobilization may be best suited toward increasing the length of the muscle tendon unit. These exercises may be performed before the dynamic warm-up of a strength training session or as a stand-alone session.

JOINT STABILITY

Most of the training applications described so far have been major compound exercises with high force demands. It has been shown that local muscles such as the rotator cuff and deep trunk muscles lend themselves toward work capacity (i.e., endurance) training because they are composed of a higher proportion of type I (slow twitch) fibers (16). Neglecting the development of local musculature may result in the preferential recruitment of global musculature in some athletes during tasks with high force demands, potentially compromising joint stability.

Based on this principle, developing work capacity (WC) of the rotator cuff complex may also be important for ensuring optimal GHJ stability. This may also be developed through high-volume–low-load training, typically using exercise involving GHJ internal/external rotation because this is the primary movement of the rotator cuff complex. Work capacity of the deep trunk muscles (erector spinae group, multifidus, and quadratus lumborum) have been shown to be crucial for spinal health (5). The role of the spine has been defined as the "ability to create, absorb, and transfer force and motion to the terminal appendicular segment during the performance of skilled motor tasks (28)." Therefore, to perform these functions during paddling, both the global (internal/external obliques and rectus abdominis), muscles of the lower and upper back (trapezius, rhomboids, and latissimus dorsi), and local (erector spinae group, transverse abdominis, quadratus lumborum, and psoas major) trunk muscles must cocontract optimally. The global muscles may not directly contribute toward segmental motion but create greater torques by moving the thoracic spine in relation to the lumbar spine (10). To train both the local and global trunk stabilizers to stabilize the spine as well as transfer force across the kinetic chain, it may be required to develop trunk WC through long-duration static holds (prone, supine, and lateral). Isolated WC testing of the rotator cuff complex and trunk may be conducted to assess the need to develop this quality (see Figure 4).

Because of the multidirectional nature of canoe slalom and the complexity of movements at the spine, multiplanar anti-movements (resisting movement in the sagittal, frontal, and transverse planes) may also be used to develop trunk stability during tasks involving movement of the upper limbs, as is the case during paddling. Exercises such as barbell roll-outs (antiflexion/extension), dumbbell farmer's walk variations (antilateral flexion), and seated landmines (antirotation) may be used for this function (Figure 5). These exercises may also develop the trunk's ability to generate force and develop stiffness (resist compliance against high external forces), which is required during whitewater paddling. As canoeing involves being in a seated position, narrowing the base of support may better prepare the trunk for the demands of the sport. It may be more suitable to initially perform trunk exercises with a wider base of support, before progressing to a narrower base of support. For

Figure 6. (A) Single-arm dumbbell farmer's walk. (B) Seated landmine. (C) Barbell roll-out.

instance, a standing landmine may be progressed to a seated landmine (Figure 6).

CONCLUSION

From the authors' experience, developing a technical framework has numerous benefits, when leading to any S&C program. (a) It allows lead practitioners to drive strategic direction across a network or department. It is important when working with multiple S&C coaches to give ownership to other practitioners to program for athletes, while working toward identified outcomes and measures. (b) Through the development of a framework, S&C coaches may develop an in-depth understanding of the sport and rationalize all elements of the program against established outcomes, within the technical framework. This is beneficial for gaining buy in toward aspects of the program or even the S&C program as a whole. For example, upper extremity strength training is culturally ingrained in canoe slalom, but lower extremity strength training is often seen as lacking relevance for the sport. After conducting a needs analysis and developing a technical framework, it was demonstrated how lower extremity training may benefit canoe slalom paddlers. (c) A technical framework may allow practitioners to develop knowledge of the functional anatomy and physiology underpinning program design. This may provide practitioners with more flexible solutions, based on individual athlete's needs, while working toward clear outcomes. (d) Finally, the process may highlight key areas of professional development for practitioners.

Conflicts of Interest and Source of Funding: The authors report no conflicts of interest and no source of funding.

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