# BIOMECHANICS OF THE "SNAP-DOWN" FOR COACHES

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Already back in1989, the gymnastics scientist Dr. P. Brüggeman, PhD. wrote that gymnasts train so much that further improvement in performance could only be achieved by improving the quality of the training and not by more time in the gym. Improving the quality of the training can only be achieved with knowledge of the biomechanics of the skills (Brüggemann, 1989). This is undoubtedly still true today. The snap-down is an important technical element in modern gymnastics and therefore we should study the forces and timing to improve the quality of our teaching. In this way, we can improve the performance of our students without more training.

A snap-down is a gymnast quickly closing the angles in hers or his shoulders and hips from a handstand, accelerating the feet down towards the floor. Europeans call it a "kurbet". A snap-down is an important element in tumbling, but also vaulting, and is even closely related to the "tap" swing on bars. We gymnastics coaches believe that the phase from handstand to standing upright during a round-off or back handspring is a very important technical element. The ability to make a fast muscle contraction to change the hip angle determines the speed of rotation of the body as a whole, and thereby the initial angular impulse during a take-off or dismount that is decisive for the height that can be achieved. In other words, being able to make a snap-down or tap swing with a powerful closing of the hip angle is essential for a high salto or dismount (Knoll & Zocher, 1979; Knoll, 1981).

First some definitions: lowering the arms towards the legs, closing the shoulder angle is **shoulder extension**. Lifting the arms over the head, opening the shoulder angle, is **shoulder flexion**. The upper body and legs moving towards each other is **hip flexion**, closing the hip angle. **Hip extension** is when the upper body and legs move away from each other towards an arched shape. So a snap-down is **hip flexion** with **shoulder extension**.

The famous head coach of Soviet and Russian Olympic teams, Leonid Arkaev, and gymnastics scientist and coach Nikolai Suchilin wrote that in principle, only movements in the shoulders and hips are permitted in gymnastics (Arkaev & Suchilin, 2004). Other movements cause an execution deduction, particularly in women's gymnastics, for example bending the knees or elbows. In current gymnastics technique, this is a truth with qualifiers. Coaches today expect pelvic **retroversion** in a hollow shape, tilting of the pelvis backwards tucking the seat under, and **anteversion,** tilting the pelvis forwards in an arched shape, when there is flexion and extension in the hips. Flexion and extension in the shoulders have a hollow chest or an arched upper back added without risking execution deduction. Retroversion of the pelvis will further close the hip angle and anteversion would open this angle. Hollowing the chest can close the shoulder angle and opening the chest can open the shoulder angle, each without actually changing the angle in the shoulder joint itself. These accompanying movements to bending and straightening the hips or shoulders makes these movements potentially bigger, faster, and more powerful. Moreover, judges do not deduct for tilting the pelvis when opening or closing the hip angle and hollowing or arching the chest when opening or closing shoulder angle. So Arkaev and Suchilin's remark is still valid. But in many acrobatic skills, bending the knees, ankles, or elbows will still cause execution deductions. In what follows, closing the angle in the hips between the trunk and legs includes any retroversion of the pelvis and opening of the hip angle includes some anteversion. Correspondingly, closing the angle in the shoulder between the arms and trunk implies hollowing the chest as well, and opening the shoulder angle implies arching the thorax too, "opening" the chest.

Some gymnastics coaches talk to their students about a "snap-down" movement tumbling or vaulting. This name emphasizes the fast, downward movement of the feet. Other coaches prefer to emphasize a fast rise of the upper body by calling the same movement a "snap-up". Both are valid and have their appropriate place in teaching technique. For example, "snap-up" would be particularly appropriate when the feet land higher than where the hands were during the handstand phase, for example a round-off up onto a springboard. Here, I define a snap-down or snap-up as the gymnast's movements between the instant the hands touch the floor and the instant the feet hit the floor during a back handspring or round-off. I will use the term snap-down hereafter, all while remembering that <u>both</u> a powerful descent of the feet and a fast rise of the upper body are important. A snap-down involves both a closing of the shoulder angle, shoulder extension, and a closing of the hip angle, hip flexion, while the entire body is rotating over the hands. Therefore, this important gymnastics technique can be performed with no execution deduction.

**Force, Impulse, and Angular Momentum**

Biomechanical analysis of skills like a snap-down moves gymnastics technique away from personal experience, belief approaching superstition, or opinion, and towards objective criteria for improving skills. Understanding the mechanics and the bio-physics is obviously not easy, as even experts make errors (Knoll, 2004; Brüggemann, 1983, 1989). However, a deeper understanding should be a goal of every coach, and a clear presentation of the biomechanics is the responsibility of gymnastics scientists.

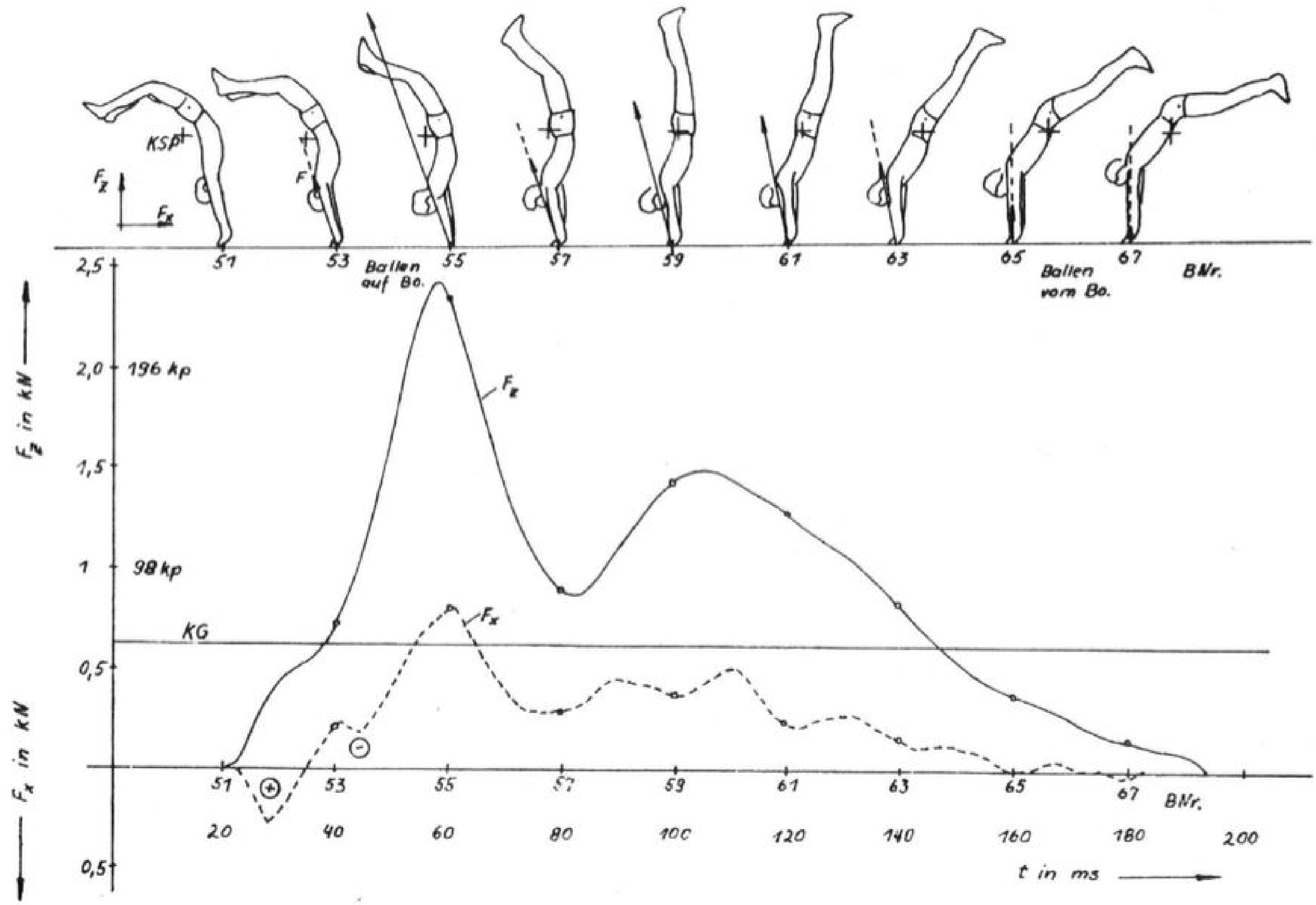


Fig. 1. Body shape changes and forces during a back-handspring snap-down to a tucked double back salto. The numbers under each figure in the series is the photo number in the high-speed film. The film tracings above are synchronized with the force-time data below them. Each dot on the force-time curve shows the force at the time of the picture above it. Time runs from left to right in 1/1000 seconds. Force is graphed up and down on the left side. In the force-time curve below the tracings of the gymnast, the solid line is the vertical force (Fz) and the dashed line is the horizontal force in the direction of the tumbling pass (Fx). The first tracing of a gymnast at the top left shows the gymnast at approximately 20/1000 seconds when the fingers first touch the floor for the handstand phase of  the back handspring. On this tracing, the cross marked “KSP” is the location of the gymnast’s center of mass, Fz is the part of the force

acting solely in the vertical direction, and Fx is the part of the force acting solely in the horizontal direction of the tumbling pass. The solid arrow pointing up from the hands is the vertical force. The dashed arrow pointing up from the hands is the force in the forward-backward direction, negative in the direction of the tumbling pass. The length and direction of the arrow in each tracing shows the direction and amount of force acting to flip the gymnast and lift him up. In Fig. 1. the amount of vertical force in thousands of Newtons is the vertical line on the left side above 0. The amount of horizontal force in thousands of Newtons in the direction of the tumbling pass is the vertical line on the left side below 0. The horizontal line marked “KG” is the gymnast’s body weight in Newtons standing still. A Newton is a measure of force equal to a 1 kilogram weight (2.2 lbs.) accelerated at 1 meter per second squared (over 3 ft. per second squared). The force data are from a plate dynamometer attached to a 1978 era foam block competition floor. From Knoll & Zocher, 1979.

A mental trick that makes complicated skills easier to understand is to think of a force moving a gymnast as made up of parts, acting together, but in different directions. These “parts of a force” are forces acting in 1) the up-down, or vertical, direction, 2) the forwards-backwards direction of the tumbling pass, or horizontally, and 3) the left-right direction, laterally. Together, these three **partial forces** make up the **resultant force** acting on the gymnast. This biomechanical technique has proved its value for centuries. For the purposes of our snap-down, the forces in the up-down, or vertical direction, and the forwards-backwards, horizontal direction of the tumbling pass are the interesting ones. In Fig. 1., we focus on the vertical (Fz) and horizontal (Fx) parts of the total floor reaction force.

The velocity of the body in the straight upwards direction, vertically, at the instant the gymnast becomes airborne determines how fast the gymnast will rise. This **vertical velocity** is created by a **vertical impulse** exerted during contact with the floor. An impulse is a force multiplied by how long the force was acting. The vertical impulse is this impulse acting straight up or down only. The vertical impulse is graphed by the total area under the force-time curve of the handstand phase of the snap-down in Fig. 1. between pictures 51 and 67. This picture represents the mathematical procedure that calculates how much and how long force is acting vertically. The total vertical impulse is the area under the solid black lined curve between pictures 51 and 67 in Fig. 1. The instant the hands leave the floor, the gymnast is no longer accelerating upwards. The gymnast can only accelerate upwards when a force is acting on hers or his body, and this is only when there is contact with the floor. The mass of the gymnast as well as the vertical velocity before the hands take-off also influence the vertical take-off velocity, together with the vertical impulse.

How fast the gymnast turns over is the visible sign of the gymnast's angular momentum. **Angular momentum** is the amount of flip that a body has at any instant in time. Angular momentum is the product of a body's rotational **inertia** multiplied by the **rotational velocity** around an axis. Inertia is the resistance to change in a body's movement. Rotational inertia is the resistance to turning a body around itself. In other words, angular momentum is how much force is required to rotate a body, multiplied by how fast the body is rotating. In our case, the axis is the contact point between the hands and floor (see Fig. 1.). During a snap-down, the body turns around the hands until the hands leave the floor. The gymnast's angular momentum is determined by the **angular impulse**. An angular impulse is a torque multiplied by how long that torque acts. A **torque** is a force that turns a body. When the impulse acts in a direction beside the center of mass of the gymnast, a torque is created that turns the body. In this case, we call it an angular impulse. The bigger the angular impulse, the faster the angular velocity, or the greater the inertial mass, or both. The inertial mass describes how much force is necessary to make that body turn and depends on the weight of the body parts and the body shape, for example tuck or layout. Once airborne, the gymnast's angular momentum essentially remains the same until landing because in practice only gravity is acting on the gymnast until landing. An impulse is a force times how long the force acts. So a gymnast can increase her impulse by either pushing harder, or longer, or both. In gymnastics, a longer push is rarely effective. To make a bigger impulse, and thereby move faster, a gymnast usually needs to push harder, with more force, not longer.

**Snap-down Biomechanics**

The data in Fig. 1. were recorded August 10, 1978 of the gymnast H.B., possibly Olympic Champion Holger Behrendt. Fig.1. shows the double peak in the vertical force (Fz) curve typical of acrobatic gymnastics skills, regardless of whether the feet or hands are hitting the floor or vault table. The peak vertical force is almost 2,500 Newtons, or close to four times his body weight, pushing through the arms. The duration of this handstand phase was 180/1000 of a second. The flight phase that follows this handstand phase of a snap-down, in other words <u>after</u> picture 67 in Fig.1., is typically very short, 0.108 sec. for a back tuck, and even shorter for a double back (0.094 sec.) (Brüggemann, 1983).

The horizontal force component (Fx) begins between pictures 51 and 53. Picture 55 is the instant the heels of the hands hit the floor and the heels of the hands lift off the floor between pictures 65 and 67. Notice that this floor reaction force is acting <u>against</u> the direction of the gymnast's tumbling pass, even at the very end of the handstand phase (picture 67). Therefore, according to the action-reaction principle (Hochmuth, 1981), the muscle effort of the gymnast is acting <u>in</u> the horizontal direction of the tumbling pass. By picture 53, the direction of this force has changed to accelerating the gymnast in the direction of the tumbling pass. This is the opposite of what happens during the take-off to a back salto where the gymnast's effort reduces her angular momentum a lot, sometimes 50% (Brüggemann, 1989). To the observer, this brief braking force during the snap-down looks like the gymnast is pulling his body over his arms with shoulder extension and hip flexion once past the vertical. This leads to the conclusion that there is a muscular force closing the shoulder angle, controlled by the gymnast (Knoll & Zocher, 1979).

Knoll and Zocher (1979) found that the effort in the hips to close the angle between upper body and legs delivers most of the angular impulse around the transverse or horizontal axis when the feet touch-down at the end of the snap-down. During a snap-down, the arms are mainly eccentric active, resisting the big vertical forces (Fz); 3.6 times body weight in the example in Fig. 1. Note that the force of gravity is acting in the same direction, adding to this vertical force. Pushing the hands against the floor is important for the hip movement by creating a solid support to transfer the floor reaction forces. Only by the last fourth of the snap-down, when the vertical reaction forces decrease to approximately body weight, does an elbow extension begin, together with a push from the shoulders. The part of the total angular moment created by the arms, because of the length of the lever arm, contributes part of the total angular moment. The angular moment in picture 67 is a third of body weight, compared with more than double body weight in picture 61, but still approximately 25% of picture 61. The maximum rate of change in hip angle attains a very rapid 840°/second just 13/100 seconds after floor touch down when the body shape has become straight (picture 64). Then the change in hip angle is slowed to the transfer of the partial angular impulse to the rest of the body. The angular acceleration curve attains its highest positive value at the start of this movement. Immediately after landing in a handstand, big muscle forces have to be created. However, this movement is supported by the inertial force produced by the horizontal support (Fx). The legs hanging back when the hands touch down creates a long path for acceleration. When this important technical element is small or missing, as often happens in the round-off snap-down, a snap-down can only be executed with limited success. The quick closing of the hip angle during a snap-down therefore has greater importance than is often believed (Knoll & Zocher, 1979).

There is an unexpectedly high effect from deceleration during the braking phase at the end of the hip angle closing movement. Within 55/1000 seconds, a slowing down of the angular velocity ( $\boldsymbol{\omega}$ ) of the change in hip angle of -25,000 degrees per second squared had been achieved. This value is negative because the gymnast's rate of shape change is slowing down. Here, gravity is working against this braking force. The maximum value attains 15,000 degrees per second squared during the following acceleration phase. These facts support the conclusion that slowing down the swing of the legs to transfer impulse requires not just the ability to coordinate movement, but also substantial strength and power (Knoll & Zocher, 1979).

Knoll (1981) emphasized the important role of closing the hip angle for all dismounts from a long hang, vaulting (Yurchenko and Tsukahara type vaults), as well as back tumbling during floor exercise or balance beam. For Dr. Knoll, a snap-down and a tap swing are biomechanically very similar. The ability to make a very quick muscle contraction to close the hip angle determines the speed of rotation of the entire body. This speed of rotation in turn determines the size of the initial angular impulse that determines the achievable height of the dismount or salto take-off.

The change in angle between upper body and legs in the hips during two, very different skills were compared by Knoll and Zocher (1979): the “tap” forwards to a triple back dismount from the rings, and the snap-down during a back handspring to a tucked double back. The results were surprisingly similar in these two, very different skills, each performed with excellent technique. In both skills, the maximum velocity of hip angle change occurred immediately after the body was in a straight shape (180° hip angle, picture 64 in Fig. 1.). On the other hand, the maximum acceleration of the upper and lower bodies towards each other happened before the straight shape. This in turn means that the greatest muscular moment had to occur before there was a 180° angle in the hips. In the case of the snap-down, this happens during the phase immediately after the hands contact the floor (see picture 55 in Fig.1.). The timing of the peak acceleration supports requiring the technical element that the body arch happen before the beginning of the acceleration in order to create the greatest possible initial force, as well as the longest possible path of acceleration. We pay particular attention to the arch extending from the shoulders to the lower back during the snap-down. The required 180° hip angle must be achieved at the latest 20-30° after the vertical. The big contribution from slowing down (negative acceleration) the legs requires not just coordination ability, but also strength and joint mobility to transfer this deceleration to the rest of the body. This sequence of muscle actions is also known as a “wind-up” or counter-movement (Knoll & Zocher, 1979) and works as described by the biomechanical principle of reaction (Hochmuth, 1981). Muscles can shorten faster with more force if they are first actively stretched. This stretch-shorten action of the muscles is basic to the plyometric effect.

Brüggemann (1983) investigated the contributions of the average vertical segmental inertial forces to the take-off to a backwards flipping salto. He found that the trunk, because of its large mass, was responsible for the majority of the total impulse, and therefore the height of the salto. We can assume that the angular inertia of the trunk has the same effect on the impulse at the end of a snap-down. Moreover, because of the greater inertia of the trunk compared to the legs, when the hip flexors act, the legs will move faster and farther than the trunk.

The timing of the maximum acceleration of the change in leg-trunk angle supports the technique requirement of an arched shape before this acceleration begins. This is necessary 1) to create the necessary initial force and 2) to be able to use a longer path of acceleration. This arch from shoulders to lower back is particularly evident in a snap-down. A straight body shape must be attained at the latest when the body is leaning 20 to 30° past the vertical (Knoll & Zocher, 1979). The more active flexibility the gymnast has in shoulder (hyper-) flexion and hip extension, the more the muscles that create the snap-down movement can be stretched prior to contracting, producing a higher initial force, greater acceleration, and thereby faster snap-down.

**Purpose of a Snap-Down**

When tumbling, during the take-off to backwards flipping saltos, the angular momentum of the gymnast is always reduced, sometimes by quite a lot (Brüggemann, 1989; Knoll, 2004). As much as possible of the initial angular momentum must be retained in order for there to be enough angular momentum to create the desired number of saltos in the air, in the desired shape. Creating, or at least retaining angular momentum is one of the functions of the back handspring's snap-down. If the snap-down is at the end of a round-off, angular momentum must be created. If the snap-down is during a back handspring that follows a round-off, retaining the already existing angular momentum is a goal. A snap-down is a key technical element in both retaining or increasing angular momentum. The ability to make a very quick muscle contraction to close the hip angle determines the speed of rotation of the entire body. As a result of their investigations, Knoll and Zocher concluded that, "The ability to make a fast muscle contraction to change the hip angle determines the speed of rotation of the body as a whole, and thereby the initial angular impulse during the take-off or dismount, decisive for the height that can be achieved." (Knoll & Zocher, 1979).

Brüggemann (1989) showed that after the snap-down, for example doing a back tuck, the body is rising during the entire take-off to the back salto. This rise actually starts during the snap-down, justifying the term "snap-up". As the entire body rotates during the snap-down, this causes the upper body to rise relative to the gymnast's feet or the floor. Depending on the angular momentum of the body, the feet are forced down onto the spring floor with increasing force. Notice the head rising between figure 59 and 67 in Fig. 1. The vertical force (Fz) from the arms pushing is an important addition. This fact is also important for strength training.

Peak vertical force during a back salto take-off after a snap-down determines the height of a back salto. Peak vertical force during a back salto take-off after a snap-down is similar to what is observed in the take-off of elite track-and-field long jumpers. This is unexpected because the horizontal velocity of the gymnast is much lower than that of the long-jumper. The difference is made up by the global rotation of the gymnast during a snap-down (Knoll & Zocher, 1979; Brüggemann, 1989). This is a very important fact because this means that the gymnast's angular momentum immediately prior to take-off is decisive for the height of the salto, not just the amount of flip. Brüggemann (1989) concluded that both high horizontal velocity and great angular momentum during the execution of the skills preceding acrobatic back flipping skills were essential for successful back tumbling.

Given the importance of being able to close the hip angle quickly to rotate the entire body during a snap-down, this has important implications for conditioning. The muscles that close the hip angle therefore need to be trained as prime movers and not simply as "core stabilizers".

**Why Teach Pike Shapes?**

Given that the ability to make a snap-down with a powerful closing of the hip angle is essential for a high salto, the next question is how much should the hip angle close? During the 2016 USA Gymnastics National Congress, National Team coaches A. Alexov and I. Ivanov lectured on front and back tumbling. They explained that at the National Training Center, they were teaching very pike shaped round-offs and handsprings for more powerful tumbling. They were teaching a snap-down that finished in a very piked shape in a round-off before a back handspring. Given the biomechanics of a snap-down, this is a good thing.

The speed of rotation of the body has an important effect on the vertical impulse that creates the height of an acrobatic salto. The faster the body can rotate, the greater the impulse, and consequently, potentially higher flip (Knoll & Zocher, 1979). The inertial resistance to flipping a pike shape is less than that of a relatively straight body shape. Therefore, a pike shape can be flipped with less force, or more importantly, with a given force, faster (Hochmuth, 1981). A pike will turn over faster than a straight shape with the same angular impulse. And we know from the biomechanics that turning over faster (greater angular momentum) results in a greater angular impulse and higher vertical forces during the take-off, essential for high saltos, vaults, and dismounts.

A piked shape at the end of a round-off snap-down into a back handspring also has a potentially longer path of acceleration than a straighter shape as is the case when the gymnast finishes a snap-down landing in a more upright stance. The biomechanical principle of optimal path of acceleration is an objective criteria for assessing the usefulness of a movement. The instant of maximum possible acceleration determines to what degree the time available for acceleration can actually be utilized to accelerate when the rules or characteristics of a skill impose a limitation. Therefore, with a given force, the longer the path available to accelerate, within biological limits, the higher the end velocity. Moreover, the geometry of the path should be straight, or evenly curved, but not undulating (Hochmuth, 1981). Beginning a back handspring from a more piked shape instead of upright stance makes possible a longer, evenly curved path of the body through space into an arched body shape, resulting in more acceleration, a higher end speed, a greater vertical force during take-off, and consequently higher saltos.

The ability to make a very quick, strong muscle contraction to close the hip angle increases the speed of rotation of the entire body, therefore some coaches object to a piked snap-down. Coaches often see a snap-down with a shape change that is too slow. The reason for this is a slow closing of the hip angle and a peak acceleration too late during the snap-down. How a gymnast performs a skill is highly determined by the gymnast's physical abilities (Knoll & Zocher, 1979; Arkaev & Suchilin, 2004). A good, effective snap-down requires exceptional strength in the hip flexors. Instead of suggesting a more upright airborne shape, the muscular effort of closing hip and shoulder angles to produce high angular acceleration, earlier, should be emphasized. The huge vertical force that must be absorbed by the arms when the hands touch down also requires exceptional strength. Otherwise, the push with the arms will be too late and too slow, in turn making the snap-down appear slow and ineffective. Another common technical error is the gymnast never arching before closing the hip angle. This will also look like a slow and ineffective "pike down". Focus instead on an actively arched shape of the entire body when the hands first touch down, followed by a powerful closing of the hip angle.

**Potential Improvements**

The snap-down illustrated in Fig. 1. dates from 1978. The bent knees in pictures 51 to 57 in Fig. 1. could cause an execution deduction. There are probably changes that could make this snap-down have an even greater effect. During the handstand phase of the snap-down, getting the resultant force (F) directed more in the horizontal direction of the tumbling pass could increase the gymnast's horizontal velocity, and thereby the kinetic energy available for more height and flip during the take-off. Potentially the greater the active joint mobility in the shoulders and upper body in picture 51 of Fig. 1., the more initial hand placement could be directly under the center of mass of the gymnast. This could reduce the braking force between pictures 51 and 53, thereby retaining more of the original horizontal velocity and angular momentum of the gymnast.

The greater the active joint mobility in the shoulders and upper body, the potentially longer the available path for acceleration. The gymnast's movements could be made bigger with more pelvic retroversion between pictures 61 to 67. The same goes for more hollowing of the chest. Bigger shape changes could give a longer path of acceleration and a higher end velocity. This would also be important in the phase of the snap-down illustrated in picture 51 of Fig. 1. A bigger change in hip angle would also make a longer path of acceleration.

Returning to Arkaev and Suchilin's (2004) remarks that only movements in the shoulders and hips are permitted in gymnastics: the ability to make a quick closing of the hip or shoulder angle with a strong muscle action is essential for floor exercise tumbling and vaulting, and does not have an execution deduction.

**Practical Coaching Recommendations**

- Separate and target development of snap-down technique and coordination of the movements from the development of the specific physical abilities necessary for a good snap-down (flexibility and strength). Attempting to develop the strength and flexibility necessary for a good snap-down with snap-down drills is inefficient and risks overuse injury. Use snap-down drills to improve technique and coordination. Use weight training to develop strength and power and stretching to improve joint mobility.
- Develop maximum strength and power in hip flexor muscles (psoas major, iliacus, rectus femoris) prior to many repetitions of snap-down drills. Typical exercises are leg lifts, from long hang or from L shape. In gymnastics skills, the rectus femoris is at least as active as a hip flexor as knee extensor.
- Develop maximum strength and power in shoulder extension muscles (latissimus dorsi, posterior fibers of the deltoid, teres major) prior to many repetitions of snap-down drills. Lat pull downs with straight arms would be a typical exercise.
- Develop maximum strength and power in elbow extension muscles (triceps brachii, anconeus) and shoulder elevation (levator scapulae, trapezius) prior to many repetitions of snap-down drills. Incline bench press or military press would be typical exercises.
- Develop shoulder mobility in active (hyper-) flexion prior to many repetitions of snap-down drills. Gymnasts should be able to move their arms backwards <u>past</u> their head in an upright stance. In a handstand, gymnasts should be able to actively open their chest and shoulders without collapsing in their lower back. In addition to stretching, prone shoulder (hyper-) flexions lifting weight or military press would be typical strength exercises.
- The shape change from active arch to pike should be powerful, fast, and at the latest, no more than 30 degrees past the vertical. A snap-down to a whip-back would ideally begin before the vertical.
- Teach pike shapes in tumbling, emphasizing big, fast shape changes.

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