NCI Assignment Task # 1
Time Motion Analysis
Instructor: Greg Wells

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Figure Skating – Past and Present

Researchers are currently studying the sport of skating to determine which energy system is used most and the relative intensities required of each specific system. Previous studies have indicated that figure skating requires maximal to supra-maximal physical capabilities. These high levels of intensity lead to fatigue, interfering with motor control, muscular coordination, and further maximal efforts. With the use of a heart rate monitor, researchers have concluded that skaters enter a competitive performance with an elevated heart rate, reach maximum levels within one minute and maintain this raised heart rate for the duration of the program.

One interesting note is that the energy demands on skaters have changed over the years, a result of the changing scoring/judging system. The performances of the early 1900's to the 1950's were comprised of numerous maximal to supramaximal elements all strung together with very little stroking or connecting steps (recovery intervals).

Therefore, this type of program required an athlete's performance to be performed very close to maximum and required all three energy systems to be well developed.

Environmental factors (small skating rinks) were likely responsible for style of skating. Also, the fact that judges stressed the technical elements vs. than artistic ability led to skating programs developed around solely the technical elements. This lead to many "firsts" performed. For example, Axel Paulsen was the creator of the well-known axel jump and Dick Button was the first to land the double axel in the 48 Olympics in St. Moritz. Other jumps, now technical and commonplace in all programs, were also being created in this era. See below chart for reference.

Jump	# of Revolutions	1st Skater to complete the element in competition			
		Male	Year (M)	Year (F)	Female
Axel	Single	Axel Paulsen	1882	1920	Sonja Henie
	Double	Dick Button	1948	1953	Carol Heiss
	Triple	Vern Taylor	1978	1988	Midori Ito
Loop	Single	Werner Rittberger	1910		
	Double	Karl Schafer	1925		
	Triple	Dick Button	1952		
Lutz	Single	Alois Lutz	1913		
	Double	Karl Schafer	1925	1942	Barbara Ann Scott
	Triple	Donald Jackson	1962	1978	Denise Biellman
Flip	Double/Triple	Terry Kubicka	1930	1981	Katrina Witt
Salchow	Single	Ulrich Salchow	1909	1920	Theresa Weld
	Double	Gillis Grafstrom	1926	1937	Cecelia Colledge
	Triple	Ronnie Robertson	1955	1962	Petra Burka
Toe Loop	Triple	Thomas Litz	1964		
	Quadruple	Kurt Browning	1988		

Through the 1970's to the early turn of the century, skating changed. Programs were constructed with an undefined number of elements and much artistry. This type of program, again, required all three energy systems, but placed less stress on the high-energy phosphate system with fewer overall elements and more emphasis on the aerobic oxidative with more stroking, connecting steps and dynamic movements (more recovery time between elements). The latter elements listed, made up the artistic merit and counted for 30% of the judge's total score. So the jumps included were few but considered "risky" while the artistic movements were polished movements with aesthetically appealing lines, positions and grace.

In 2004, skating again changed as a new judging system was implemented by the International Skating Union. In fact, you could say that skating performances have changed back from the aesthetic and less technically demanding programs of the past 40 years to the technical demonstrations seen in Button era – albeit with more challenging technical elements.

Technical elements are now awarded a base score and then a panel of technical specialists assign an additional score ranging from -3 to +3 for difficulty. In order to make a triple jump more difficult for example, the skater will perform it near the end of their program. This means that skaters need to complete difficult elements later in the program when their bodies are experiencing high levels of fatigue.

As triple jump early in the program is no different than a triple jump late in the program, the question is one of fatigue. A triple jump planned later in the program makes the element more difficult simply due to fatigue. And this means more points with the new judging system.

Energy System Demands in the New Era of Skating

This new style of program composition requires altering the physical conditioning that was once necessary for past winning programs. Skaters are still rewarded for skating skills, transitions, footwork, performance execution and choreography, however the bulk of their points are obtained from the technical scoring of their program – this often determined before they even step on the ice (due to the program's composition). What remains is that the athlete has to be in good enough condition to perform the program and gather all the difficulty points that they can.

Choreographing a program has become a strategic task and the conditioning of the skater a critical component. The skater, coach, choreographer and strength and conditioning trainer work together now more than ever. Figure skaters still need to have all three energy systems well conditioned; however, there is more utilization of the high-energy phosphate system at a time in the program when the body is beginning to feel the accumulative effects of fatigue. The aerobic base of a skater must also be well conditioned to sustain a high level of performance for 2 ½ to 4 minutes (and to recovery quickly during short scheduled breaks – such as field moves or stroking - from the high intensity efforts). Depending on the program, the anaerobic glycolytic energy system is still critical for optimal performance as spin positions are now sustained for longer durations - another difficulty factor added with the new judging system. Although, we are not aiming to beat the Guiness World Record of 115 revolutions by Swiss skater Lucinda Ruh, spins can last up to 26 seconds in duration and comprise of 10-12 revolutions per foot in a combination spin. This is twice as long a spin performed in the past with double the number of rotations,

while attaining more original and creative positions, without losing velocity during transitions to a new position.

Skaters who wish to successfully complete a four minute or longer program with intricate footwork, complex choreography (dynamic arm, hip, head and torso movements) and 8 or more technical elements (as set out by the ISU for the short program), aerobic and anaerobic conditioning is a must. The extent to which the energy systems (high-energy phosphate, anaerobic glycolytic and aerobic oxidative) are utilized in a program depends on the intensity demands, built-in recovery intervals, and overall choreography of the program.

Since all skating programs are relatively short (2.5 or 4 minutes in duration), the primary source of energy is produced through the anaerobic glycolytic system – although all three systems do their fair share of the work. Strategically choreographed programs produce high-energy phosphate stress through highly technical elements (jumps, spins, stroking, and footwork).

The table below details the elements included in figure skating programs and the respective energy systems required in performing each element. This example is taken from Shizuka Arakawa's 2006 Olympic Short (2:48) Program. For more information on Arakawa, see Appendix A.

*Shizuka Arakawa's 2006 Olympic Short Program

Skating Elements and Energy Systems Required (short program 2:48 minutes)
High Energy Phosphate Predominant Elements
▪ Combination jump (planned triple lutz/triple toe, performed triple lutz/double toe loop) ▪ Triple flip ▪ Double axel
▪ Combination Spin – death drop entrance/camel layover/donut ▪ Layback/Biellman spin ▪ Combination Spin – back camel/change of edge/camel/donut/back sit/change of feet/forward camel/layback/Biellman
Anaerobic Glycolytic Predominant Elements
Footwork
Continuous stroking, skating, crossovers, choreography
Aerobic Oxidative Predominant Elements
Serpentine spiral sequence (forward leg raise – left outside edge, element continued on inside edge, element continued with hand release, backward Biellman position right foot raised)

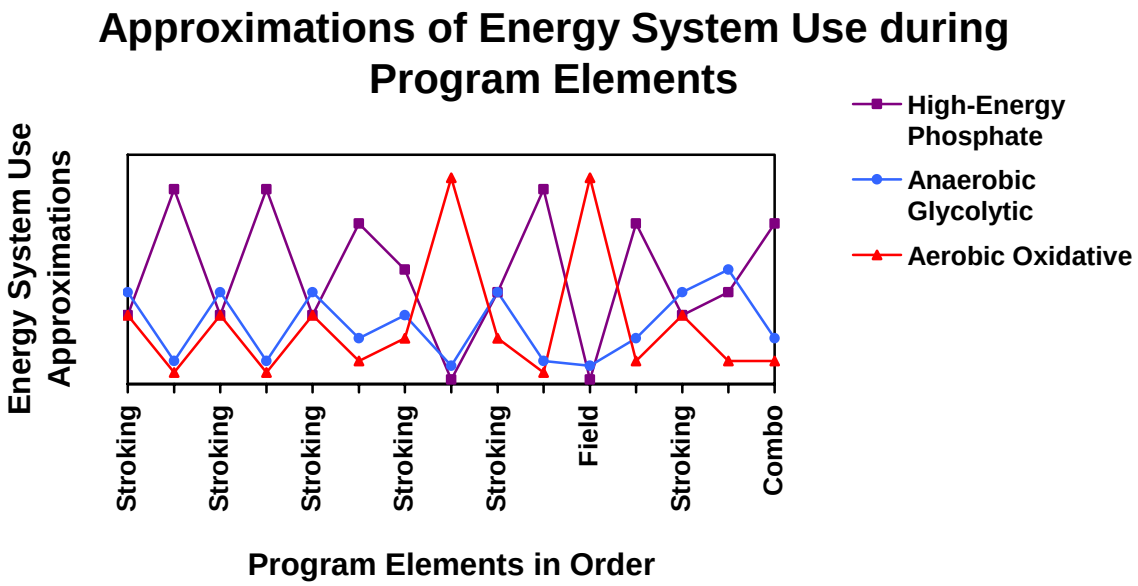
* To watch this performance, click here: http://www.youtube.com/watch?v=JURiHuVXiyI

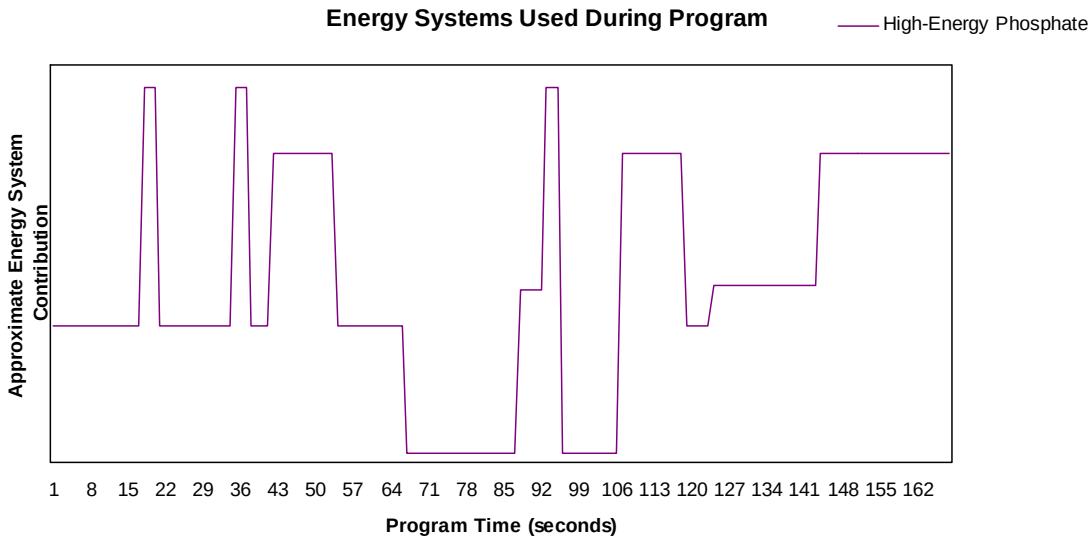
In the chart below, I've included each element as it was performed in Arakawa's program. Note the element, the energy system demands, the duration of each, and the recovery intervals (less strenuous elements) choreographed in the program.

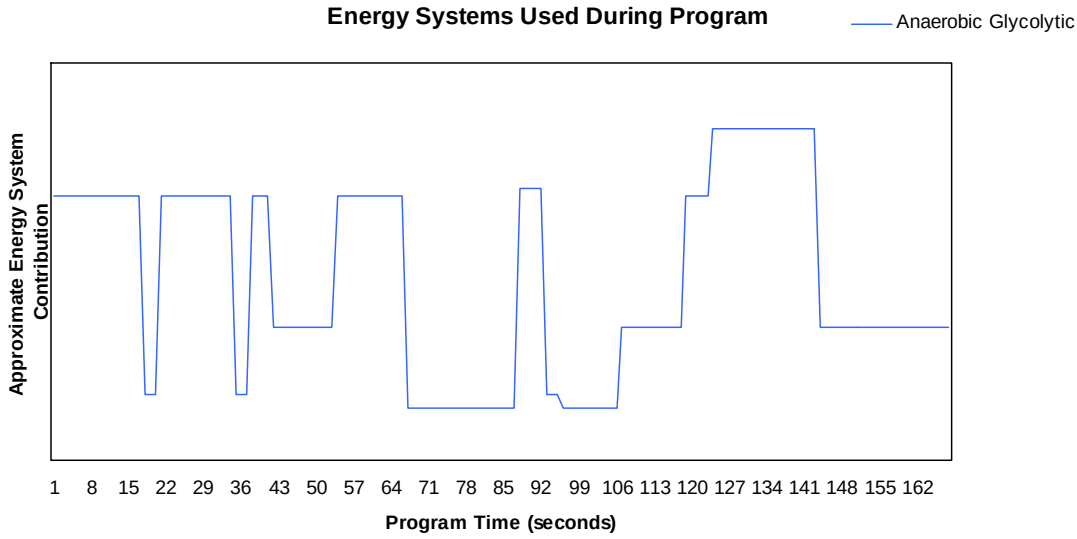
Time (mm:ss)	Duration (seconds)	Intensity	% of Element time to total Program time	Element
0-17	17	H	10	Fast Stroking
*17-20	3	H	2	Triple Lutz/Double Toe
20-34	14	H	8	Fast Stroking
*34-37	3	H	2	Triple Flip
37-41	4	H	2	Fast Stroking
*41-53	12	M	7	Combo Spin 1. Death Drop Entrance 2. Layover Camel position 3. Donut position
53-1:06	13	H	8	Fast Stroking
*1:06-1:26	20	L	11	Spiral Sequence 1. Forward Leg Raise – inside edge 2. Forward Leg Raise – outside edge 3. Forward Leg Raise – inside edge, no hand 4. Backward Biellman position
1:26-1:31	5	M	3	Medium Stroking
*1:31-1:34	3	H	2	Double Axel
1:34-1:44	10	L	6	Field Moves
*1:44-1:56	12	M	7	Layback/Biellman Spin
1:56-2:01	5	L	3	Slow Stroking
*2:01-2:21	20	H	11	Footwork
*2:21-2:48	27	M	16	Combo Spin 1. Back Camel position 2. Change of Edge 3. Donut position 4. Back Sit 5. Change of Foot 6. Forward Camel 7. Layback 8. Biellman position

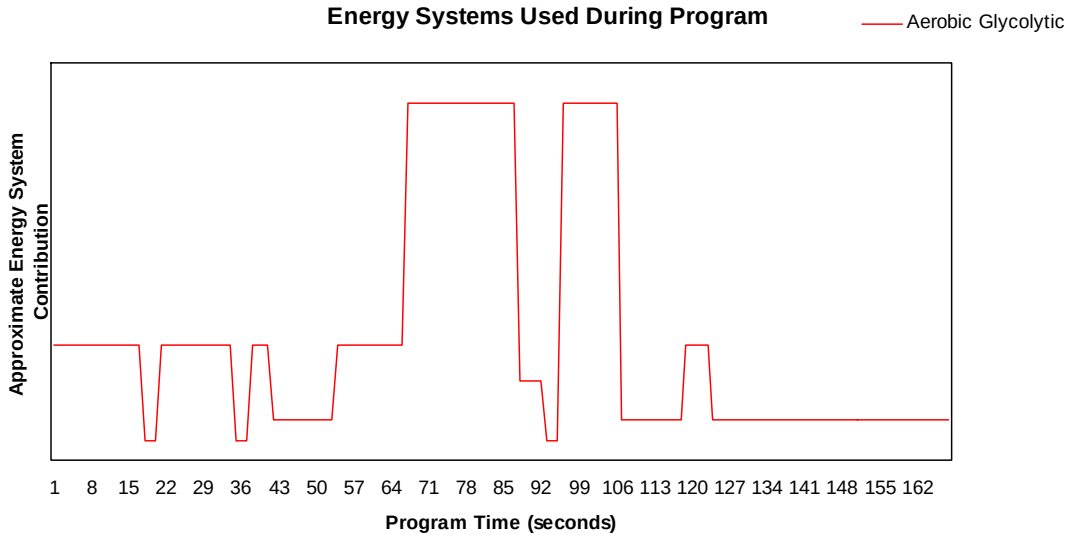
*These elements are required elements in the short program as determined each year by the International Skating Union (ISU).

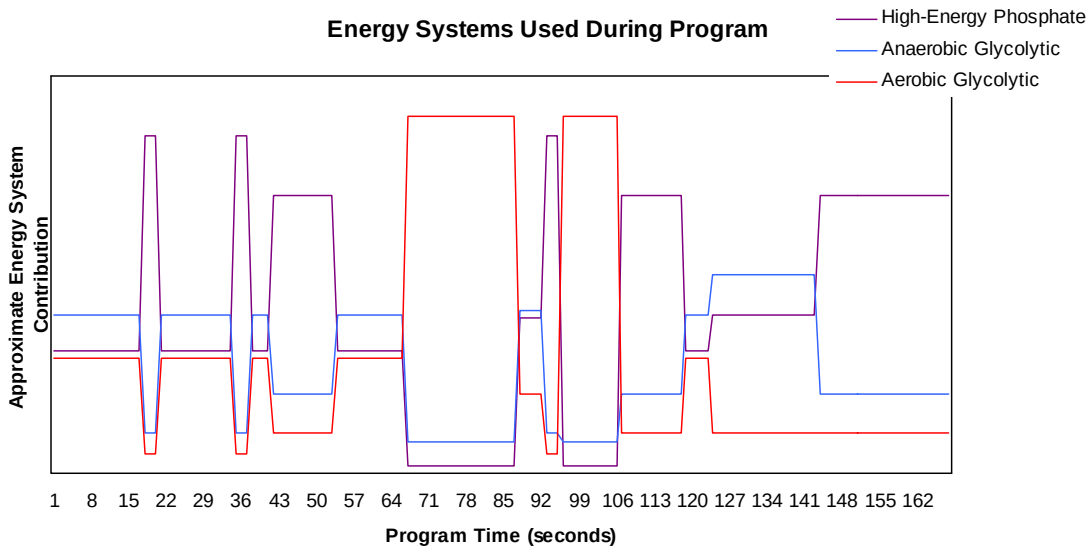
From this table you can see how easily a program can be broken down into the 3 energy systems with only a stopwatch and video camera. With this information a specific training plan can be developed including strength, power, flexibility and energy system conditioning that is necessary to perform the program.


Approximations of Energy System Use during Program Elements
Energy System Use Approximations
High-Energy Phosphate
Anaerobic Glycolytic
Aerobic Oxidative
Stroking
Stroking
Stroking
Stroking
Stroking
Field
Stroking
Combo
Program Elements in Order


Energy Systems Used During Program
High-Energy Phosphate
Approximate Energy System Contribution
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162
Program Time (seconds)


Energy Systems Used During Program
Anaerobic Glycolytic
Approximate Energy System Contribution
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162
Program Time (seconds)


Energy Systems Used During Program
Aerobic Glycolytic
Approximate Energy System Contribution
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162
Program Time (seconds)


Energy Systems Used During Program
High-Energy Phosphate
Anaerobic Glycolytic
Aerobic Glycolytic
Approximate Energy System Contribution
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162
Program Time (seconds)

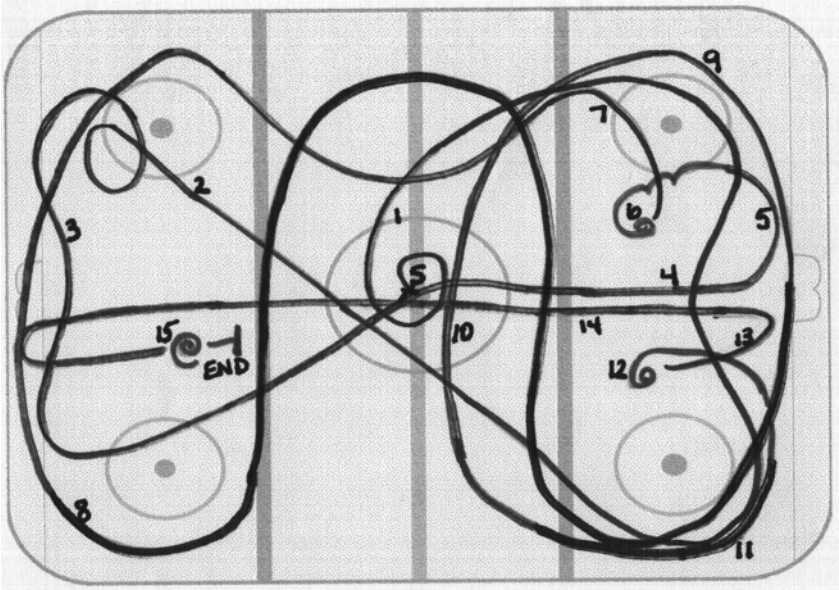
Time: Pause: Intensity in Figure Skating

In the time-motion analysis chart below, I've included time:pause:intensity values for the program, which is representative of high level programs in the era of the new judging criterion. This chart will give a good indication of the rest, pause, and intensity performed during modern-day programs.

1.	Total Time (E+P time of play)	2:48
2.	Total Exercise Time	2:48
3.	Total Pause Time	0:00
4.	% exercise time of total time (ex/total x 100)	100%
5.	% pause time of total time (pa/total x 100)	0%
6.	Range of duration of exercise period	2:48
7.	Range of duration of pause period	0
8.	Average of duration of exercise period	2:48
9.	Average of duration of pause period	0
10.	Exercise to pause ratio (ave ex:ave pau)	2:48:0:00
11.	Total time of high and/or low intensity exercise	H2:08 :L 40
12.	Total time of particular movements	Indicated in chart above
13.	% of high vs. low intensity exercise time of the total exercise time	H 76% L 24%
14.	% of particular movement time of the total exercise time	Indicated in chart above
15.	Total distance covered during exercise	Difficult to determine
16.	Total distance covered during high vs. low intensity exercise	Approximations can be derived from movement diagram below
17.	Total distance covered during particular movements	Approximations can be derived from movement diagram below
18.	% distance covered by high and/or low intensity exercise of total distance	Approximations can be derived from movement diagram below
19.	% distance covered during particular movement of total distance	Approximations can be derived from movement diagram below
20.	Average velocity (total distance/total time)	Undetermined
21.	High and/or low intensity velocities (intensity distance/intensity time)	Undetermined
22.	Total number of repetitions of high and/or low intensity exercise	N/A
23.	Range of heart rate during exercise	Depends on athlete can vary between 116-210bpm
24.	Any changes in intensity over the course of an event	N/A
25.	Changes and trends in length of exercise or pause periods over the course of the competition (due to fatigue or change in strategy)	lower intensity movements elements choreographed between high intensity elements for recovery

Detailed Movement Analysis Diagram

In this chart below, I've done a detailed movement analysis diagram to illustrate Arakawa's movement patterns and program elements during her short program.



Legend

	Intensity	Element
1.	H	Fast Stroking
2.	H	Triple Lutz/Double Toe
3.	H	Fast Stroking
4.	H	Triple Flip
5.	H	Fast Stroking
6.	M	Combo Spin 1. Death Drop Entrance 2. Layover Camel position 3. Donut position
7.	H	Fast Stroking
8.	L	Spiral Sequence 1. Forward Leg Raise – inside edge 2. Forward Leg Raise – outside edge 3. Forward Leg Raise – inside edge, no hand 4. Backward Biellman position
9.	M	Medium Stroking
10.	H	Double Axel
11.	L	Field Moves
12.	M	Layback/Biellman Spin
13.	L	Slow Stroking
14.	H	Footwork
15.	M	Combo Spin 1. Back Camel position

		2. Change of Edge 3. Donut position 4. Back Sit 5. Change of Foot 6. Forward Camel 7. Layback 8. Biellman position

Training For Skating

As you can see, a well designed aerobic oxidative conditioning plan for a skater will incorporate both the cardiovascular and pulmonary systems. The reason for this is shown with the use of a heart rate monitor. Before skaters even begin their program they experience elevated heart (range from 108-150 bpm) and respiratory rates due to increased anxiety levels and also from their off-ice warm-ups. As a skater begins their program their heart rate reaches maximal levels (can be as high as 210 bpm) in approximately one minute and stay maintain this maximal level for the entire duration of the program. Further, endurance training programs have been shown to reduce HR at each workload during skating programs (both long and short) with a more consistent successful completion of elements.

Yet a focus exclusively on the aerobic system is a mistake. The high energy demands of such a program (a program using all three energy systems) require an ability to produce higher blood lactate concentrations at max, buffer the rapidly accumulating hydrogen ions, manage fatigue, and produce explosive actions both at rest and under fatigued conditions. These demands go beyond mere aerobic training and require a mix of explosive C-P system training (for improved C-P and nervous system activity and high intensity interval work (Anaerobic-Glycolytic system efficiency and both anaerobic and aerobic enzyme upregulation).

As lactate accumulates (reflective of increased glycolytic demands and high H+ accumulation), this leads to tight, burning sensations in an athlete's legs and/or arms a short while into their program. This may impair jumps, especially of the takeoff leg. The fatigue that sets in can also cloud judgement and concentration, resulting in errors and missed elements. And with the new judging system there is no room for this type of mistake.

In the end, conditioning for figure skating must be practical, balanced, sport specific and include energy efficient work that mimics the energy required to perform the programs that year (short and long). The biggest challenge is balance as skaters are often skating for 6 hours per day, working on skills. In addition, dance, ballet, and choreography work (off-ice) is included. Therefore additional conditioning in the form of aerobic, anaerobic, or strength and power work must fit it without causing overtraining.

Below, I've included an annual mesocycle which offers an example training program that could be used for a high level skater to develop sport-specific conditioning.

	Mar	April	May	June	July	Aug	Sept	*Oct	*Nov	Dec	*Jan	Feb
Skating Skills -practice (hrs/wk)	20	22	25	25	22	20	18	15	15	18	15	15
Choreography (hrs/wk)	5	3	2	1	0	1	2	2	1	0	2	0
Aerobic (hrs/wk)	3	3	2	1	1	2	2	2	2	2	1	2
Anaerobic Glycolytic	1	1	2	3	3	2	2	1	1	2	1	1
C-P	3	3	2	2	2	2	2	2	2	2	1	1

* Months that contain qualifier competitions.

Aerobic Activities include:
Biking, jogging, swimming, rowing, rollerblading

Anaerobic Glycolytic Activities include:
Circuit training, longer duration intervals (biking, sprinting etc.), higher repetition strength training, power skating

C-P Activities include:
Low repetition explosive and maximal strength training, medicine ball tosses, plyometrics, short duration intervals (biking, sprints etc.)

As the competitive season approaches activities become more and more sport specific. During the competitive season total volume of exercise training decreases.

Assessing the Efficacy of the Program

As all programs need to be tailored to the individual, I have a system of assessments that help determine the efficacy of the system and which training components may need to be altered to produce a better result. Below are the assessments I regular perform.

1) Body Composition
2) Heart Rate Data
3) Balance and Coordination
4) Muscle Strength
5) Muscle Endurance
6) Anaerobic Performance
7) Aerobic Performance

I've chosen the preceding indicators for the following reasons:

1) Body Composition
    a. Regular assessment of body composition is important for two reasons. First, as skating is an aesthetic sport I need to ensure that my athletes are staying lean while maintaining the lean mass required to perform all of the critical elements in a program. Secondly, body composition tells me whether my athletes are fuelling enough and/or fuelling properly for performance.
    b. If body fat is accumulating, it's likely the result of overfeeding or poor nutrient partitioning (which can accompany overtraining if stress hormones are predominating). If lean body mass is dropping, it's likely the result of underfeeding protein or total energy or overtraining (if appetite is negatively affected). Both scenarios can be remedied rapidly – but it requires objective data such as total body mass, body fat %, regional skin fold data, and fat to lean mass ratios.

2) Heart Rate Data
    a. Heart rate data collected at rest, during off-ice training, and during on-ice training (via heart rate monitors) can give clear indicators of fatigue.
    b. A depressed resting heart rate and a decreased heart rate per work load can indicate potential parasympathetic overtraining. An increased resting heart rate and an increased heart rate per work load can indicate potential sympathetic overtraining.
    c. Further, a morning Rusko test can give some indication of risk of overtraining.

3) Balance and Coordination
    a. As athletes accumulate fatigue and either the nervous system becomes affected or total energy stores in the body drop, balance and coordination are impacted.
    b. Balance and coordination can be assessed visually both on ice as well as during stability work off-ice.

4) Muscle Power and Strength
    a. As we regularly assess and train to develop muscle strength, I monitor this for regular adaptation. If an athlete is not developing strength (especially relative strength), we investigate potential problems including inadequate nutrition, inadequate recovery, inadequate programming or adherence, etc.
    b. Strength tests include bench press, dead lifts, squats, chin ups (unweighted or weighted as necessary), and dips (unweighted or weighted as necessary). Power tests include 40yd sprints, medicine ball tosses, and speed work at 40% of 1RM (bench press and jump squats).

5) Muscle Endurance
    a. As we regularly assess and train to develop muscle endurance, I monitor this for regular adaptation. If an athlete is not developing muscular endurance, we investigate potential problems including inadequate nutrition, inadequate recovery, inadequate programming or adherence, etc.

b. Muscle Endurance tests include 75% of 1RM to failure for the following: bench press, dead lifts, squats, chin ups and dips.

6) Anaerobic Performance
    a. As we regularly assess and train to develop anaerobic performance, I monitor this for regular adaptation. If an athlete is not developing anaerobic power and maintenance, we investigate potential problems including inadequate nutrition, inadequate recovery, inadequate programming or adherence, etc.
    b. We use 2 cycle ergometer protocols (6x10 second repeats; and 1x30s effort) to determine anaerobic performance.

7) Aerobic Performance
    a. Although I don't have athletes do much direct aerobic work (aside from practice on the ice), anaerobic training and on-ice training should improve aerobic performance. If an athlete is not developing good aerobic power and maintenance, we investigate potential problems including inadequate nutrition, inadequate recovery, inadequate programming or adherence, etc.
    b. Aerobic performance is assessed using a VO2 running test.

Appendix A

Athlete: Shizuka Arakawa
Born December 29th, 1981 in Shinagawa, Tokyo, Japan
Height 5'6" (currently one of the tallest female skaters)
Coach: Nikolai Morozov (from Belarus)
Previously coached by: Tatiana Tarasova and Richard Callaghan (coached Todd Eldredge, Tara Lapinski) and Kumiko Sata (Yuko Sato's mom)
Lives and trains at the International Skating Center of Connecticut in Simsbury, USA
Landed first triple at age 8 – triple toe loop

Competitive Highlights

Year	Olympic Games	World Championships	Four Continents	Japanese Nationals
1996				1st
1997				1st
1998	13th			1st
1999			6th	1st
2000				5th
2001			6th	2nd
2002	Did not make Japanese Olympic Team		2nd	2nd
2003		8th	2nd	3rd
2004		1st		3rd
2005		9th		
2006	1st			3rd
2006	Retired from the sport May 7th, 2006			