ISSN : 0974 - 7435 Volume 10 Issue 7

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(7), 2014 [2098-2108]

Kinematics analysis-based synchronized swimming lift preparation technologies' gravity center relative parameters research

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ABSTRACT

Synchronized swimming is Chinese competitive sports event of potential advantages, the event elegant postures establish on the harmonious lift technologies, and athlete gravity center kinematical parameters change status in lift technologies preparation process is the key to preparation technologies perfect fulfill or not. On the basis of stating synchronized swimming event lift technologies difficulty factors, the paper ascertains gravity center stability and importance influences, and takes three women national level master sportswomen's two lift one and then the one lifts another one, three lift one as well as three lift one up and down these three kinds of lift forms motion process as examples to make empirical analysis, obtained data result and analysis results conform to practice, it can apply the paper researches methods to research on individual athlete, in the hope of providing theoretical basis for its training schemes' improvement.

KEYWORDS

Kinematics parameter; Video analysis; Gravity center extraction; Displacement speed; Accelerated speed; Synchronized swimming.

INTRODUCTION

Synchronized swimming is called "water ballet", the sport is originated from the thirties of 20th century, in the beginning, and it is used as water exhibition event in the interval of swimming competitions, and prevails over France, Germany and other European countries. In recent years, Chinese synchronized swimming technology has been greatly promoted, the paper researches o the event lift preparation technologies players' gravity center kinematics parameters, in the hope of providing scientific materials for athlete training.

For synchronized swimming technical research, during Chinese scholars, lots of people have made efforts, these scholars proposed views has guided synchronized swimming technical training to a certain extent. Among them, Zhang Li-Qin and others (2013) pointed out synchronized swimming events special features showed in competition rules changes, energy metabolism and athlete competitive ability three aspects, competitive rules changes propelled to movement develop toward "quick, strong, difficult" orientation, put more emphasis on physical ability and artistic expression, movement possessed aerobics and anaerobic metabolism mixed functions, and anaerobic metabolism became more and more important, high level movement competitive ability performed as superb physical ability, comprehensive refined technology, skillful and effective tactics and strong mental and intelligent advantages[1]. Xu Jian-Fang and others (2010) tested on synchronized swimmers that participated in 11 sports meeting preliminary contest to understand before and after major competitions athlete functions change status and competition intensity, and got conclusion that participated athletes before and after competition functional states overall changes were insignificant, synchronized swimming team and duet event competitions intensity could arrive at lactic acid training intensity and synchronized swimming duet event had higher physical ability[2]. Mu Wei (2013) analyzed synchronized swimming world three main competitions team free routine technical arrangement during 2008~2011, pointed out Chinese team needed to update ideas in artistic arrangement, continue to give its advantages into play, it should have some new recognition on difficulty understanding in arrangement, and highlight subject in whole set of motions arrangement, skillful arrange and design synchronized motions[3].

On the basis of formers researches, the paper researches on synchronized swimming lift technology preparation process gravity center kinematics parameters, in the hope of exploring more effective movement training schemes.

SYNCHRONIZED SWIMMING LIFT TECHNOLOGY DIFFICULTY ELEMENTS ANALYSIS

Xu Jian-Fang and others (2012), synchronized swimming was a competitive sports event proceeding in water that integrated dance and music, it possessed intense artistic appeal, it not only required athletes had excellent physical ability quality, high level special ability and stronger artistic expression, but also it required the whole set of motions having higher difficulties and fluency, arrangement and music should express strength, speed and beauty perfect combination that could intense appeal to referees and audiences[4]. In synchronized swimming event, lift and somersault techniques are the supporting technologies of the event, are highlights of expressing the whole team cooperative technology, which can let synchronized swimming to have more innovation, interests and thrills. Due to the event competition rules stipulate that athlete cannot fulfill motion with the help of bottom pool during competition, they can only rely on water treading motion generated support force to fulfill lifting, which let synchronized swimming technologies to have certain difficulties, and water acts supporting reaction force on athletes, and meanwhile it will generate flowing, so, athletes puzzle about how to improve synchronized swimming lift motion quality and difficulty aspect.

On this basis, the paper makes analysis, according to lift motion internal technologies, external visual effects and sports item competition rules, it extracts lift technology difficulty elements. As Figure 1 shows lift motions difficulty elements constitution structural chart.

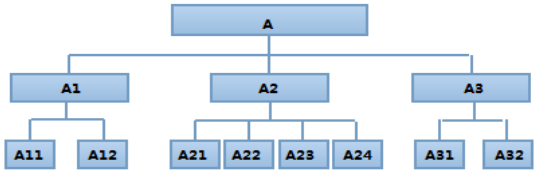

Figure 1 : Lift motion technical difficulty elements structural graph

Symbol description in Figure 1 is as TABLE 1 show.

TABLE 1: Figure 1 symbol description table

Symbol	Content	Symbol	Content	Symbol	Content
A	Lift motion difficulty elements	A11	Population element	A23	Supporting height
A1	Staff element	A12	Figure element	A24	Supporting lever
A2	Supporting element	A21	Supporting points amount	A31	Language element
A3	Posture element	A22	Supporting area	A32	Aesthetic element

Difficulty elements contents statement

Staff is participant in sports; participants have different tasks according to different roles classification that mainly divide into foundation and top. To staff element importance, it is classified as basic difficulty element. Jiang Shan (2013) pointed out, population element is judged from absolute quantity and relative quantity two perspectives, absolute quantity refers to overall people amount that participate in lift motion that affects style occupied space, image and complex degree, relative quantity refers to top and foundation people amount ratio, figure element contains members' heights and figures[5].

In A11 element relative quantity, if number of top is above number of foundation, difficulty in fulfilling motions will be larger, in A12 element top and foundation figures have relative relations that when foundation players lift their figures considerable top players, motions complex degree and technical precise degree have high requirements, on the contrary, when top height and weight is greatly lower than foundation players, it not only is hard to reflect foundation players' technologies and strength, lift motion required human body motion's strong, strength and beauty cannot be expressed.

Supporting element in synchronized swimming lift technologies refer to the process that top gets supporting from foundation players body parts and supports transferring, supporting element is composed of supporting amount, area, height and supporting lever four aspects elements. In physics principles, it has rules that supporting area gets bigger, top to foundation pressure will get smaller, if it wants to easy to carry out lift motions, it needs to increase supporting points amount, after supporting points amount increasing, balanced control will be easier, and motions will also more stable, which can be enlightened form formula (1):

$$P = F / S \quad (1)$$

A23 element, on one hand, it refers to lift absolute height that is the height that supporting point from ground, if foundation lies in standing position, then it can measure supporting point landing in foundation all fours or trunk concrete positions, absolute height gets higher, its technological contents will be larger, and corresponding difficulties will also be larger.

A24 elements refers to athlete individual lever motion, athlete skeleton can be regarded as rigid body structure is composed of skeleton support and connective articulation points, articulation points can be thought as supporting points, as Figure 2 shows human body upper arm lift process lever principle schematic diagram.

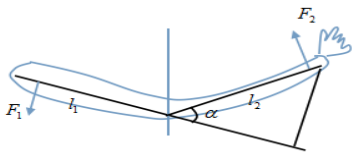

Figure 2 : Upper arm lift lever principle schematic diagram

In Figure 2, variables have relations as formula (2) shows:

$$F_1 l_1 = F_2 l_2 \cos\alpha \quad (2)$$

If synchronized swimmers can skillful apply lever principle, he can build foundation for his successful and perfect lifting.

Zhou Jia-Yin and others (2006) pointed out,posture was human special expression,was a kind of cultural symbol that loaded people thoughts and emotions[6]. In synchronized swimming event, lift posture refers to human body presented basic patterns in lift motions, it contains A31 element and A32 element, as TABLE 2 shows above two factors definitions.

TABLE 2 : Language factor and aesthetic factor

Language factor	Language factor refers to lift motions expressed implied meanings, with respect to oral or written language, motion language expression is more vague, implicit, every lift posture is a kind of motion vocabulary, it expresses different messages, is the reflection of cultural background, era features, and also is concentrative presentation of athlete competitive ability, whether lift motion can be clear and vivid, let audiences to recognize hidden property relations from motions or not is the reflection of athlete technical levels and difficulty values.	Aesthetic factor	Aesthetic element refers to lift motions artistic appeal, human body posture forms a series of dynamic images from limbs moving surrounding corresponding joints, the aspects of motion symmetry, comparison, extension, rhythm, metre and others compose into lift posture style beauty, flowing beauty, harmonious beauty, flavor beauty and so on, let audiences heart and mood to be pleased, attract aesthetic experiences, feel sports charms, and whether lift posture can strike a chord from audiences, present plentiful,full and active flexible states that people look forward or not is testing at athlete comprehensive levels.

To sum up, staff is basic difficulty element, supporting is core difficulty element, posture is difficulty loading element.

Lift motions technical training notes

Lv Yi-Sheng (2003) pointed out that improving motion basic structure was an important path to improve sports technology overall levels[7]. Lift motions technical links divide into shelve, pose and removing off shelves, in the three links, it needs to pay attention to exertion, cooperation and buffer. In the following, it explains the three items of notes, in the hope of providing references for synchronized swimming training.

Exertion

Exertion is the key to lift motions victory, and exertion training is the beginning of lift motions training, due to in competition process, athlete needs to instantaneous fulfill positions transformation from low to high and let body to form into certain style, athletes exertion orders are lower limbs pedal to ground and exert --> waist and abdomen transmit strength--> upper limbs uplift and present motions, their exertion features are short and controlled, in lifting process, athletes need to instantaneously give lifted object an initial speed, the force cannot be so strong, is a process of gradually increasing, in the hope of letting lifted objects not to separate from lift athletes controlling range, keep exertion states in

the whole process, it cannot have sluggish processes. In physics, exerting object needs to have the aid of acting party reaction force to let bearing object motion state to change or deform by acting force effects.

Cooperation

Fulfillment of lift motions need to fulfill by two people cooperation at least, lift participated athletes skillful cooperation, orderly motions, internal consumption reduction can form into resultant force and generate synergistic effect, and can also let members different abilities to be balanced developed. In theory, according to Newton's second law as formula (3) shows, cooperative training main contents have motions rhythms, exertion size, orders and orientations training so on, all have a reasonable accelerated speed controlling.

$$\sum \mathbf{F} = \mathbf{ma} \tag{3}$$

Buffer

Buffer is way of protection and steady, it cannot be ignored in lift technologies, dropping process after top player being lift, it has impulsive force on ground, the impulse may hurt athletes, theorem of momentum in physics can explain the phenomenon, top player speed changes in the air is active effects of force, speed change quick or slow and size are up to acting force size and acting time long or short, in buffer process, on one hand rely on foundation players applying specific motions to absorb partial impulsive forces as receiving, blocking or embracing ways, stretch out upper limbs in the face of top dropping trajectory, in the following apply self lower limbs muscle tension to alleviate impulsive force, on the other hand, top should make self-protection, pull in the chin, straighten head, protect head and spine, utilize lower limbs hip, knee, and ankle three main joints surrounding muscle groups successive rhythmic deformability contraction, reasonable utilize lower limbs "compression loading" and "twisting loading" to effective reduce impulsive forces. That is to say, extend acting force acting time in top player body; lengthen displacement of actual impacting process.

$$\mathbf{I} = \mathbf{F} \cdot \mathbf{t} = \mathbf{mv}_1 - \mathbf{mv}_0 \tag{4}$$

HUMAN BODY GRAVITY CENTER POSITION EXTRACTION

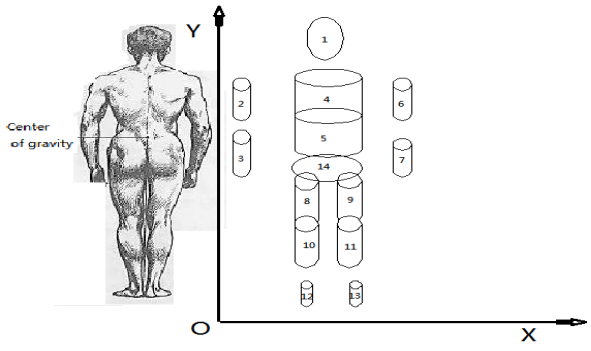

Figure 3 : Swimmers' rigid body link structural model

As Figure 3 shows, it divides human body into 14 rigid body links, the body each link mass center relative position is supposed to be unchanged, according to definite proportion component, it solves each link mass center relative position:

$$\begin{cases} \mathbf{x}_{\updownarrow} = (1-\mathbf{n})\mathbf{x}_{\uparrow} + \lambda \mathbf{x}_{\downarrow} \\ \mathbf{y}_{\updownarrow} = (1-\mathbf{n})\mathbf{y}_{\uparrow} + \lambda \mathbf{y}_{\downarrow} \end{cases} \tag{5}$$

In formula (1) : λ represents human body each link mass center position ratio, $(x_{\uparrow}, y_{\uparrow}), (x_{\downarrow}, y_{\downarrow})$ respectively represent human body each link upper and lower joints points coordinates, $(x_{\updownarrow}, y_{\updownarrow})$ represents human body each link mass center coordinate.

Human body all links suffered gravity resultant acting point is called human body gravity center. According to rigid model in (1),decompose human body each link, when swimmer moves, every posture will have a gravity center position, its gravity center position is solving by moment composition principle, as formula (6) shows:

$$\left(X_G = \frac{\sum_{i=1}^{14} G_{xi} \times x_{i\updownarrow}}{\sum_{i=1}^{14} G_{xi}}, Y_G = \frac{\sum_{i=1}^{14} G_{y_i} \times y_{i\updownarrow}}{\sum_{i=1}^{14} G_{y_i}} \right) \quad (6)$$

In formula (6) : (X_G, Y_G) represents swimmer body gravity center coordinate, $(x_{i\updownarrow}, y_{i\updownarrow})(i = 1,2,3,\cdots,14)$ represents each link mass center coordinate, $\left(\frac{G_{x_i}}{\sum_{i=1}^{14} G_{x_i}}, \frac{G_{y_i}}{\sum_{i=1}^{14} G_{y_i}} \right)$ is each link relative mass in coordinate direction.

TABLE 3 : Chinese youth human body each link mass center definite proportion component and relative quality percentage table

Young male			Young women		
Human body link part	Definite proportion component	Relative mass	Human body link part	Definite proportion component	Relative mass
Hand	50%	0.64%	Hand	50%	0.49%
Forearm	41.87%	1.30%	Forearm	42.72%	1.18%
The upper arm	48.6%	2.61%	The upper arm	46.91%	2.62%
Foot	44%	1.50%	Foot	44%	1.38%
A lower leg	40.91%	4.00%	A lower leg	40.63%	4.55%
Thigh	47.71%	14.00%	Thigh	45.87%	14.28%
Upper torso	53.73%	17.00%	Upper torso	54.26%	16.53%
Lower torso	40.54%	25.60%	Lower torso	47.36%	25.87%
Trunk	44%	42.70%	Trunk	44%	42.70%
Head	50%	9.30%	Head	50%	8.60%

By formula (5) (6) and TABLE 3, it can calculate free stroke swimmer gravity center position in case posture is fixed.

SYNCHRONIZED SWIMMING LIFT PREPARATION TECHNOLOGIES GRAVITY CENTER RELATIVE PARAMETERS ANALYSIS

Research objects and research methods

Research objects: Three women synchronized swimming national level master sports women, ages are respectively 22 years old, 22 years old, 21 years old, heights are respectively 169cm, 168cm, 165cm, weights are respectively 56kg, 58kg, 53kg.

Research methods

The paper adopts documents literature, video analysis method, experts interview method, mathematical statistics method and logistic analysis method as well as other research methods, from which mathematical statistic method implementation software and analysis software are SPSS and EXCEL, video analysis method experiment process is as following show:

1) Shooting required equipment are one unit underwater professional camera、one unit of normal speed Sony1080i video camera、measuring scale of calibrated frame.
2) In one hour before shooting, use calibration frame to define testing range, use two video cameras to collect data in the front of underwater observation window in diving venue, two units of video cameras principal optic axis included angles conform to shooting requirement that shooting included angle should be above 30 degree and less than 90, fix two units of video cameras focus, position, angle and height well, and keep video cameras fixation in experiment, use one video camera to do data collection in water surface; during shooting, adopt a unit of underwater professional video camera to shoot athlete full set of underwater lift preparation motions at 50fps speed, adopt a unit of Sony video camera to shoot athlete lift water motion at 50fps speed, its shooting distance is 8meter; after shooting, adopt two-dimensional motion parsing system software to do image sampling on shot motion whole process, every athlete selected every group basic paces and difficulty motions will be continuously analyzed one by one, adopt two-dimensional motion parsing system with built-in Hannah demonstrative human body model, by digital handling with human body model's 15 links and applying SIMI-motion video parsing system to do image parsing, it gets original data, adopt digital lowpass filtering method to do smoothing with original data,it gets the research required data and each indicator.

Kinematics parameters selection

The paper statistics data contents are time, space and time-space dimension these three aspects, in time dimension, selected indicator is time of fulfilling motions and time of motions each phase, in space dimension, selected indicator is each joint angle and gravity center displacements in Y axis orientations, in time-space dimension, selected indicator is gravity center speed, accelerated speed and each joint angular speed in Y axis direction. As Figure 4 shows, kinematics parameters indicator system.

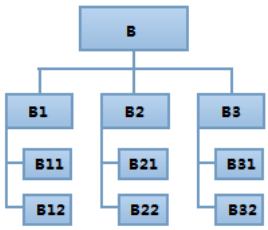

Figure 4 : Synchronized swimming lift preparation technologies kinematics parameters indicator system

Note

B. Kinematics parameters indicator system
B1. Time dimension parameter
B2. Space dimension parameter
B3. Time-space dimension parameter
B11. Motion completion time
B12. Motion each phase time
B21. Each joint angle
B22. Gravity center displacement in Y axis direction
B31. Gravity center speed, accelerated speed in Y axis direction
B32. Each joint angular speed

Gravity center displacement parameters analysis

Synchronized swimming divides into two lift one and then the one lifts another one, three lift one as well as three lift one up and down such three forms, under three athletes three kinds of lifting forms, gravity center Y axis direction top point and bottom point distance as well as top point time statistical data result is as TABLE 4 shows.

TABLE 4 : Three kinds of forms athlete Y axis direction displacement and time parameters statistical result

Athlete type	Two lift one and then the one lifts another one					Three lift one				
	Preparation stage			Release stage		Preparation stage			Release stage	
	min	max	δ	max	t	min	max	δ	max	t
A	-0.478	-0.402	0.076	-0.399	0.54	0.124	0.255	0.131	0.361	0.74
B	-0.485	-0.425	0.060	-0.432	0.56	0.169	0.315	0.146	0.349	0.74
C	-0.002	0.128	0.130	0.260	0.78	-0.121	0.050	0.071	0.058	0.50

Three lift one up and down					
	Preparation stage			Release stage	
Type	min	Max	δ	max	t
A	-0.706	0.600	0.524	0.601	2.42
B	0.042	0.599	0.557	0.563	2.44
C	-0.599	-0.027	0.572	0.012	2.55

Note : min represents bottom point;max represents top point; δ represents differences; t represents corresponding time.

By TABLE 4, obtained result is as following show:

In the lift motion of two lifting one and then the one lifting another one, three athletes gravity centers amplitude of variation is in wave, each athlete gravity center distance change has differences, A,B two athletes gravity centers distances changes have higher similarity, but they still have certain differences in two stages synchronization technology, C athlete gravity center change has certain differences from A, B athletes, but in overall two lifting one and then the one lifting another one motion technical cooperation, three athletes gravity center changes quite conform to overall technical motion exertion ways.

In the lift motion of three lifting one, three athletes gravity centers amplitude of variation is also in wave, each athlete gravity center distance change has similarity, in view of stability, B athlete is stronger than A athlete, but A athlete explosiveness is higher, A,B two athletes exerting points are quite synchronized, C athlete gravity center curve amplitude has bigger changes in two stages, release phase peak value appears earlier, from the three cooperation, it still needs to strengthen training in synchronized aspect.

In the lift motion of three lifting one up and down, three athletes gravity centers amplitude of variation is still in wave, and each athlete gravity distance change has similarity, in preparation phase, A,B athletes technology synchronization is higher, but in release phase, top point differences are larger and exertion time quick or slow desynchrony is very obvious, C athlete and other two athletes gravity center amplitudes have no bigger differences, on a whole, three athletes exertion points,synchronization and stability have larger differences.

Gravity speed parameters analysis

As Figure 5, Figure 6 and Figure 7 show, three lifting ways each athlete gravity center speed changes status.

By above three figures information, it can get conclusion as following show:

Under the lifting way of two lift one and then the one lifts another one, A, B athletes fluctuation curves are relative consistent, C athlete has obvious differences with other two athletes, B athlete speed

fluctuation is more stable than left side athlete in preliminary phase, on a whole, three athletes human gravity center speed indicators show that A, B, C athletes cooperation have differences, bottom A athlete speed fluctuation is relative fierce, which will affect its body gravity center displacement.

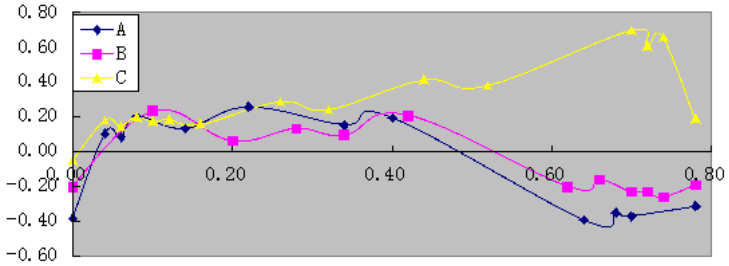

Figure 5 : Two lift one and then the one lifts another one's lifting way athlete gravity center changes status with time

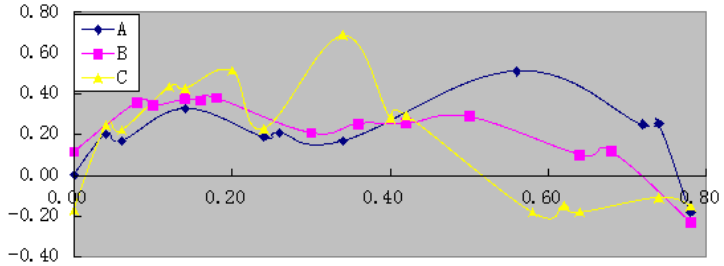

Figure 6 : Three lift one's lifting way athlete gravity center changes status with time

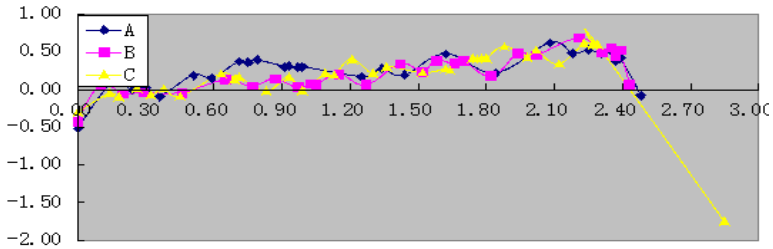

Figure 7 : Three lift one up and down's lifting way athlete gravity center changes status with time

Under the lifting way of three lift one, A、C athletes accelerated speed is relative obvious, B athlete speed fluctuation is relative smooth that has obvious differences with other two athletes by comparing.

Under the lifting way of three lift one up and down, three athletes are worse in symmetry, stability and tacit cooperation, three athletes wholly have certain similarity.

Gravity accelerated speed parameters analysis

Under three kinds of lifting ways, three athletes Y axis direction gravity center preparation phase and release phase acceleration status statistics are as TABLE 5 show.

By TABLE 5 data features, it can get conclusion as following shows:

Under the lifting way of two lift one and then the one lifts another one, A athlete explosiveness is better, three athletes in the whole motion completion process, accelerated changes have no bigger differences, combine with TABLE 4 data,it is clear that A athlete time point and gravity center peak values have differences in the maximum gravity center accelerated values, while other two athletes are relative consistent, combine with Figure 5,it is clear three athletes in case that gravity center speed arrives at maximum value, their accelerated speeds are smaller, and when gravity center speed is smaller, their accelerated speeds gets bigger.

Under the lifting way of three lift one, three athletes accelerated speed rhythm sensation are relative distinct and also relative even, A athlete relative gravity accelerated speed has been obvious increasing in the later period of preparation phase, B athlete previous and post differences are not very big, combine with TABLE 4 data, it is clear that in the view of time, gravity center accelerated speed and gravity center displacement, the gravity center accelerated speed maximum value appears after gravity center top point, comparing to Figure 6 gravity speed change trend,it is clear that in preparation phase, gravity center speed gets bigger and bigger, accelerated speed also changes accordingly, but in release phase, gravity center speed gets bigger while corresponding accelerated speed will get smaller.

TABLE 5 : Three athletes' gravity center two phases Y axis direction acceleration statistical results table

Statistics		Two lift one and then the one lifts another one			Three lift one			Three lift one up and down		
		A	B	C	A	B	C	A	B	C
Preparation phase	min	0.018	0.042	0.027	0.003	0.001	0.253	0.015	0.026	0.002
	tmin	0.40	0.28	0.30	0.14	0.40	0.16	0.77	1.50	0.32
	max	12.319	6.506	5.809	4.906	6.216	10.157	8.706	8.769	5.000
	tmax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	δ	12.301	6.464	5.782	4.903	6.215	9.904	8.691	8.743	4.998
Release phase	min	0.135	0.097	0.112	0.088	0.145	0.090	5.292	3.676	1.595
	tmin	0.66	0.74	0.52	0.56	0.64	0.72	2.39	2.39	0.72
	max	4.054	2.330	12.046	11.016	6.721	3.860	12.698	11.793	14.381
	tmax	0.56	0.56	0.78	0.78	0.78	0.48	2.44	2.44	2.84
	δ	3.919	2.233	11.934	10.928	6.756	3.770	7.406	8.117	12.786

Note: min represents minimum value; max represents maximum value; tmin represents minimum value corresponding time;tmax represents maximum value corresponding time; δ represents differences between minimum value and maximum value.

Under the lifting way of three lift one up and down, three athletes during preparation phase accelerated speed maximum values appear in motion starting phase, and accelerated speeds fluctuation frequencies are higher, in preparation phase, A、B athletes gravity center accelerated speeds differences are not significant, in release phase A athlete are relative higher, it proves the athlete explosive force is better, use TABLE 5 data and TABLE 4 data to combinative analyze, it is clear with athletes' gravity centers gradually rising, accelerated speeds are also regular fluctuating, till release phase top point, accelerated speed will also relative get bigger, these data reflected contents also relative conform to practice.

CONCLUSION

The paper based on stating synchronized swimming lift technologies difficulty elements, it puts forward training measures in exertion, cooperation and buffer phases, gets synchronized swimming lift technologies influential important contents are athlete gravity center kinematics parameters, so provides human body 14 rigid body links structural model and gravity center extraction algorithm, by empirical analyzing three women synchronized swimming national level master sportswomen two lift one and then the one lifts another one, three lift one as well as three lift one up and down such lifting ways, it gets correlation conclusion about gravity center displacement, gravity center speed and gravity center accelerated speed, conclusion has already reflected in the paper, so don't summarize it here.

The paper provided research methods that video measurement method and mathematical statistic method, as well as empirical data obtained by paper's methods relative conforms to practice, which can be used as evidence for athletes improved training methods.

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