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# Adjustment to Change in Familiar and Unfamiliar Task Constraints

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## Adjustment to change in familiar and unfamiliar task constraints

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### Abstract

The aim of this study was to assess the rate of adjustment to changes in task constraints that are familiar and unfamiliar when a change in the pattern of sequencing of segmental movements is not required. The selected task was underwater flutter kicking with flippers (familiar) and without flippers (unfamiliar). Nine male competitive age-group swimmers were assigned either to an unfamiliar “leg flipper” task, a familiar “foot flipper” task or a “control” group to perform five trials without flippers (all groups), 60 trials with flippers, and a post-test comprising 10 trials without flippers (all groups). Kinematic variables were calculated from digitized video data. Whether the movement pattern was appropriate for the task was indicated by the percent power in the fundamental Fourier frequency harmonic of the vertical oscillations of the hip, knee, and ankle, and by a “velocity index” that was defined as the ratio of the hip-to-knee and knee-to-ankle velocities of the fundamental Fourier waveform. Adjustment to reproduce the appropriate movement pattern occurred within the first block of 10 trials regardless of whether the constraints were familiar or unfamiliar. However, optimal performance in terms of swimming speed was not obtained following change to the unfamiliar constraint until after 10 trials.

**Keywords:** *Constraints, dynamical systems, inter-limb rhythmical coordination*

### Introduction

The concept of constraints is critical to the analysis of human movement (Clark, 1995). Newell (1986) emphasized that skilled performance, as reflected in the optimal pattern of coordination and control, is determined by the interaction of the organismic (e.g. height, weight), environmental (e.g. temperature, gravity), and task constraints (e.g. goals of a sport, implements or tools used during performance). A coach or teacher can manipulate the task constraints to help a performer search for functional and individualized coordination solutions (Araújo, Davids, Bennett, Button, & Chapman, 2004) and to simulate the range of conditions encountered during competition. Thus, the role of the coach in structuring task constraints and organizing practice environments is important (Araújo et al., 2004; Newell, 2003; Schmidt & Lee, 1999). By becoming familiar with different combinations of task constraints, a participant learns to adjust rapidly to changes in those constraints during competition.

The rate of adjustment to changes in task constraints is influenced by two main factors. The

first is whether the task constraints are “familiar”. Familiar task constraints could be defined as constraints that exist frequently during practice. Unfamiliar task constraints are those that are different from any of the conditions under which the task has been practised. The second factor is whether the introduction of the constraints changes the movement pattern required to optimize performance. Thus, there are four basic scenarios when constraints are changed: (1) a new pattern is required to adjust to unfamiliar constraints; (2) a new pattern is required to adjust to change in familiar constraints; (3) the same movement pattern can be used across different constraint conditions with some rescaling of parameters of the muscle synergies to adjust to unfamiliar constraints (Davids, Bennett, Handford, & Jones, 1999); and (4) the same movement pattern can be used across different constraint conditions with some rescaling of parameters of the muscle synergies to familiar constraints.

The lack of information to date regarding the number of trials required to adjust to changes in task constraints may be linked to two main issues. The first is that the optimal movement pattern required,

and therefore the extent to which the optimal movement pattern differs between the constraint conditions, was not known in most studies. The second is that the duration of most studies rarely went beyond the very first adjustment to the task and as such did not allow qualitative modifications of the behaviour to appear (Nourrit, Delignières, Caillou, Deschamps, & Lauriot, 2003).

Based on dynamical systems theory (Kelso, 1995), in which the characteristics of the muscle synergies are set to produce a movement pattern suitable to achieve the task under given constraints (Davids et al., 1999; Newell, 1986, 2003; Turvey, 1990), one might expect that the rate of adjustment depends on the time required to search the “attractor landscape” for the appropriate solution. Thus, when a new movement pattern is required and there is no experience of the particular constraints, the adjustment would be slow. This was the case in a vertical jumping task in which participants who were accustomed to jumping from a hard surface had to jump from an unfamiliar sprung surface (Sanders & Allen, 1993; Sanders & Wilson, 1992). After more than 100 trials, the participants were still adjusting their kinematic and kinetic patterns towards the optimal pattern. The movement pattern required to optimize jump height when jumping from a sprung surface was very different from that required when jumping from a hard surface, both in terms of the magnitude of the joint torques required and in their sequencing. Accordingly, the search for the optimal pattern was extensive and slow, despite the goal of the jumping task (i.e. maximizing height) remaining unchanged.

To assess the effect of familiarity of task constraints, without the confounding effect of the requirement to change the movement pattern, it is necessary to investigate the response to change in task constraints when the rudiments of the required movement pattern do not require significant change. Such a task is prone underwater flutter kicking. Efficient performance in flutter kicking in swimming is known to be associated with sinusoidal vertical motions of the body segments sequenced so that a “wave” progresses caudally along the body (Sanders, 2007). The fact that the characteristics of the optimal movement pattern are known for swimming kicking tasks provides an opportunity to assess the rate of adjustment to change in task constraints when the system is not required to search the perceptuo-motor landscape for a new coordination pattern to optimize performance (Davids et al., 1999; Newell, 1996).

The use of flippers greatly changes the loading at the joints and the resistance to motion of the segments in the system, thereby creating great demand for rescaling of parameters of the muscle

synergies. However, to optimize performance the swimmer must maintain the movement pattern in which hip, knee, and ankle motions are sequenced to create a body wave that produces a rotating vortex of water that is shed to generate propulsive force (Beale, Hover, Triantafyllou, Liao, & Lauder, 2006; Colgate & Lynch, 2004; Lighthill, 1969; Triantafyllou, Triantafyllou, & Yue, 2000). Thus, the use of flippers to change task constraints meets the requirement of changing the constraints without eliciting a need to change the rudiments of the movement pattern.

Swimmers practise regularly with foot flippers, and so foot flippers provide a different but familiar task constraint environment. A new type of flipper, the “shinfin” (Shinfin Pty. Ltd., Sydney, Australia), worn on the shin, provides a different constraint environment that is unfamiliar to most swimmers. These “leg flippers” differ from the standard fins by being closer to the knee joint, thereby reducing the lever arm of the hydrodynamic forces relative to the knee joint. Also, leg flippers lie across the shin and the instep of the foot. As a result, the ankle is immobilized and the system is changed from a three-segment system to a two-segment system. Therefore, the swimmer must adapt not only to a change in the requirements for torque production, but also to change from being a system comprising three segments, in which the third segment generates propulsion, to being a system comprising two segments, in which the second segment produces propulsion and is longer than previously.

The purpose of the present study was to examine the process of adjustment to changes in task constraints, in particular the presence or absence of flippers in underwater flutter kicking in swimming. This would shed light on the effect of familiarity on the rate of adjustment to change in task constraints when the rudiments of the optimal movement pattern, in particular the sequencing of segmental contributions, remain unchanged. Given that the rudiments of the required movement pattern do not change with change in task constraints in the underwater flutter kicking task, it would be expected that the system is not required to search the perceptuo-motor landscape for a new movement solution. The adjustment to the task constraints should be achieved solely by rescaling the parameters of the existing muscle synergies. Thus, it was hypothesized that a small number of trials, relative to the number required when the movement pattern must be changed, would be required to adjust to the task constraints. Furthermore, we hypothesized that the rescaling would be achieved very quickly for the familiar flipper condition, but would take longer for the unfamiliar “shinfin” flipper condition.

## Methods

### *Participants*

Nine male squad swimmers (age 11.0–14.0 yrs; height 1.49–1.67 m; mass 35.5–51.8 kg) were recruited to participate in the study with informed parental consent and approval from the university ethics committee. Participants completed a questionnaire about their training history, including their previous use of flippers. All participants were competitive age-group swimmers with at least one year of training for competition. All had experience of kicking with foot flippers, having used them many times in training, but none had experience of using the leg flippers.

### *Research design*

Six of the swimmers were randomly assigned to either a “leg flipper” group or a “foot flipper” group. The remaining three swimmers comprised the control group. The leg flipper and foot flipper groups participated in a pre-test (pre-training) consisting of 5 trials without flippers, 60 experimental trials with their flippers, and a post-test (post-training) comprising 10 trials without flippers. To avoid the possible confounding effect of fatigue, participants were limited to 10 trials per day of testing. This meant that testing was conducted on eight separate days, one day each for pre-training and post-training, and 6 days of 10 trials per day using the flippers (T1–T6). The control group completed the pre-test and post-test only. The testing was conducted over a period of 5 weeks.

### *Video data collection*

A video camera (KY32 CCD, JVC Corporation, Yokohama, Japan) in a waterproof housing recorded the underwater motion of the swimmers at 50 fields per second. The camera was positioned perpendicular to the line of the swimmer's motion. The camera capture area was adjusted so that the entire swimmer was recorded for a minimum of three kicking cycles. A kicking cycle was defined as the period from the lowest position of the foot marker following the downbeat to the equivalent position in the next cycle.

The leg flippers were “shinfin” leg flippers (middle size). All participants in the leg flipper group wore the same size flippers (length 38.2 cm, width 22.8 cm, surface area 710 cm<sup>2</sup>). All swimmers in the foot flipper group wore “WIN” foot flippers (Principal Win Ltd., Penang, Malaysia), again of the same size (6–8: length 34.8 cm, width 19.0 cm, surface area 402 cm<sup>2</sup>).

### *Preparation of the swimmers*

Before recording, black waterproof markers were placed on anatomical landmarks on the skin surface

of the right side of the body such that an imaginary line from the camera through the marker would pass through the joint axis of rotation. Participants were asked to flex and extend the joint to assist in identifying these points while the axis was palpated by the researcher. The process was aided by identifying landmarks known to correspond closely with the joint axes of rotation. These were the greater trochanter for the hips, lateral condyle of the femur for the knees, lateral malleolus for the ankles, and the metatarsal-phalangeal joint. To estimate the camera-to-joint axis line for the shoulders, the participants emulated the prone swimming position with the arms extended in a streamlined position.

At the beginning of each session, the length of the thigh of each swimmer was measured from the centre of the hip joint to the knee joint. This length was used in subsequent scaling in accordance with the method described by Clothier and colleagues (Clothier, Payne, Harvey, Blanksby, & Benjanuvatra, 2004). For the trials in which leg flippers were worn, the experimenter fitted the flippers in accordance with the manufacturer's guidelines, ensuring consistency with regard to position and tightness of the straps.

### *Test procedure*

At each test session, swimmers swam 10 trials perpendicular to the camera axis at a distance of 8 m from the camera. Direction was alternated and only the odd trials were recorded for subsequent digitizing and analysis. This meant that the right side of the body was recorded five times during each session.

Swimmers were instructed to submerge before, and surface after, imaginary lines perpendicular to the wall from markers placed 5 m either side of the camera at the water's edge. While submerged, swimmers were required to kick with a flutter kick (without using the arms and with an alternating “left–right” kicking action similar to that used in front crawl swimming) to maximize their speed. Swimmers had at least 15 s rest between trials with the start of each trial dependent on swimmers expressing readiness to continue. Swimmers were instructed not to perform this task between test sessions.

### *Data analysis*

The landmarks were digitized manually using an APAS System (Ariel Dynamics Ltd., San Diego, CA, USA) to yield unscaled and unsmoothed two-dimensional positional data in pixel units. The period digitized was approximately 15 frames beyond either end of a kicking cycle defined as the period

between the highest points of the ankle of successive kicks. These data were then input to a custom-designed program in MATLAB (The MathWorks, Natick, MA, USA) to calculate the variables of interest.

To identify accurately the limits of the kicking cycle, the ankle data were smoothed and interpolated using a Fourier transform and inverse transform. Interpolation expanded the data set so that the highest points of the ankle joint motion, used to identify the limits of the kicking cycle and the duration of the cycle, could be calculated precisely. Once these limits had been identified, the data for all points were smoothed using a Fourier smoothing routine and interpolated to 101 points representing percent time points of the kicking cycle. The new sampling frequency, used subsequently for calculating time derivatives, was determined as 100/cycle duration. To enable comparison of the low-frequency waveforms as harmonics independent of actual frequency, four harmonics were retained in the inverse transform of all cycles of all participants. This ensured that movement patterns could be compared regardless of the frequency of the kicking cycle. The actual smoothing frequencies corresponded to between 6 and 7 Hz, depending on the kick cycle duration.

#### Calculation of variables

Two indicators of the appropriateness of the movement pattern were calculated. The first was the power in the first Fourier harmonic of the vertical undulations of the hip, knee, and ankle as a percentage of the power in the whole signal. This is known to increase with increasing skill in flutter kicking (Sanders, 2007). The second was a “velocity index”, defined as the ratio of knee–ankle (knee–metatarsophalangeal joint for the leg flipper trials) wave velocity and hip–knee wave velocity (Sanders, 2007).

*Velocity of wave travel.* The velocity of the “wave” that moved along the body as a result of cephalo-caudal sequencing of the joint vertical undulations was calculated (Sanders, Cappaert, & Devlin, 1995). Fourier phase angles for the fundamental waveform were calculated using:

$$\Phi = \tan^{-1}(B/A)$$

where  $A$  and  $B$  are the sine and cosine coefficients for the fundamental Fourier frequency. Average velocity from the hip to the knee joint and knee to the ankle joint was calculated using:

$$v = d/t_m$$

where  $d$  is the distance between consecutive joint centres, and  $t$  is the time for the wave to travel from

the proximal to distal landmark. The consecutive landmark from the knee is the ankle for the three-segment system (bare foot and foot flipper conditions) and the metatarsophalangeal joint for the two-segment system (leg flipper condition).

The time for the wave to travel from one joint landmark to the next was calculated as:

$$t_m = (\Phi_m - \Phi_{m+1})T/360$$

where  $\Phi_m$  is the phase angle of  $m^{\text{th}}$  landmark (increasing numbers in the cephalo-caudal direction), and  $T$  is the period of the cycle (for the fundamental frequency this is equivalent to the period of the kick cycle).

*Percent power of the fundamental frequency.* The amplitudes of the Fourier sine and cosine coefficients were calculated from:

$$C_n = (A_n^2 + B_n^2)^{1/2}$$

where  $A_n$  and  $B_n$  are the sine and cosine coefficients, respectively, for the  $n^{\text{th}}$  Fourier harmonic. The average power of each harmonic was calculated as  $2C_n^2$  and then the power in the fundamental frequency was expressed as a percentage of the power contained in all four harmonics comprising the signal.

*Swimming speed and kicking frequency.* Average speed of the swimmer was determined as the horizontal displacement of the hip marker during the cycle divided by the cycle time. Kicking frequency was the inverse of the cycle time.

#### Statistical analysis

A within-swimmer and within-group approach was used to investigate changes across blocks (experimental sessions) of trials and conditions. For individual swimmers in the experimental groups, this involved comparisons among the pre-training (without flippers) session, the six sessions of training trials (with flippers), and the post-training session (without flippers). For the control group, the post-training session was compared with that of the pre-training session. This was to establish the magnitude of the change that could be expected due to factors other than the experimental factors.

Magnitudes of the changes were quantified statistically using effect sizes (Cohen, 1988) relative to the pre-training session. Effect sizes were used in this study because our interest was in determining the magnitude of the effect of changing from one task constraint environment to another, rather than attempting to establish whether or not any change

was statistically significant. Cohen's (1988) guidelines were taken into account when interpreting the magnitude of changes. These were small (0.2), medium (0.5), and large (0.8).

## Results

### *Percentage power in the first harmonic of the lower extremities*

No trends were apparent across the training sessions in the percent power contained in the first harmonic of the joint vertical motions (Table I). The percent power in the fundamental frequency was very high in all sessions and variability was small. In particular, T1 was similar to all of T2 to T6.

### *Body wave velocity across hip-knee and knee-ankle*

When using flippers, the leg flipper group increased absolute hip-knee wave velocity from  $3.35 \text{ m} \cdot \text{s}^{-1}$  in the pre-training session to  $4.24 \text{ m} \cdot \text{s}^{-1}$  in T1 and also increased knee-metatarsophalangeal joint velocity from  $2.82$  to  $4.11 \text{ m} \cdot \text{s}^{-1}$ . In the case of both leg

flipper and foot flipper groups, the velocity indices were appropriate for the task and remained so for all of T1 to T6 (Table II). In the post-training session, the wave velocities and velocity indices returned to values very similar to those in the pre-training session for both leg flipper and foot flipper groups.

### *Swimming speed and kicking frequency*

Swimming speeds increased greatly when using both foot flippers and leg flippers (Table III). The leg flipper group increased speed by  $0.19 \text{ m} \cdot \text{s}^{-1}$  and the foot flipper group by  $0.24 \text{ m} \cdot \text{s}^{-1}$  in the training sessions compared with the barefoot pre-training session. This represented an effect size of 1.22 for the leg flipper group and 3.56 for the foot flipper group. For the leg flipper group, the post-training speed was  $0.02 \text{ m} \cdot \text{s}^{-1}$  less than the pre-training speed and the effect size was small ( $-0.14$ ). However, for the foot flipper group, there was a considerable reduction in swimming speed ( $0.16 \text{ m} \cdot \text{s}^{-1}$ ) and the effect size ( $-2.50$ ) was large. The maximum speeds during the training sessions for the leg flipper group were attained during session T2, while T1 had the lowest

Table I. Mean values, variability (*s*), and effect size (ES) of percent of signal power in the first harmonic hip, knee, and ankle joints over all experiment sessions for the leg flipper and foot flipper groups.

		Pre	T1	T2	T3	T4	T5	T6	Post
<b>Hip</b>									
Leg flipper	Mean	98.76	98.82	99.17	98.11	98.01	97.62	97.99	96.33
	<i>s</i>	1.11	1.09	0.72	1.58	2.15	2.20	1.54	2.33
	ES		0.06	0.37	-0.59	-0.68	-1.03	-0.69	-2.20
Foot flipper	Mean	98.87	98.06	97.62	97.92	97.78	98.13	97.28	95.51
	<i>s</i>	1.74	2.38	2.13	2.17	2.11	1.44	1.98	2.90
	ES		-0.47	-0.72	-0.54	-0.62	-0.43	-0.91	-1.93
Control	Mean	99.32							97.30
	<i>s</i>	0.77							1.95
	ES								-2.62
<b>Knee</b>									
Leg flipper	Mean	98.41	96.83	96.48	97.25	97.34	97.31	97.06	97.10
	<i>s</i>	1.60	1.43	1.59	1.63	2.32	2.10	2.53	2.84
	ES		-0.99	-1.21	-0.73	-0.67	-0.69	-0.85	-0.82
Foot flipper	Mean	98.38	98.62	98.88	98.36	98.42	99.17	98.89	97.92
	<i>s</i>	1.39	1.03	0.71	1.09	1.86	0.47	0.65	1.15
	ES		0.17	0.36	-0.02	0.02	0.57	0.37	-0.34
Control	Mean	99.50							97.79
	<i>s</i>	0.68							1.48
	ES								-2.53
<b>Ankle</b>									
Leg flipper	Mean	99.79	99.71	99.74	99.30	99.80	99.69	99.59	99.50
	<i>s</i>	0.20	0.35	0.21	0.61	0.20	0.20	0.29	0.45
	ES		-0.37	-0.25	-2.39	0.04	-0.48	-0.98	-1.41
Foot flipper	Mean	99.73	99.46	99.49	99.48	99.44	99.74	99.50	99.16
	<i>s</i>	0.42	0.62	0.48	0.49	0.74	0.31	0.47	0.71
	ES		-0.64	-0.56	-0.59	-0.67	0.02	-0.55	-1.35
Control	Mean	99.81							99.47
	<i>s</i>	0.21							0.44
	ES								-1.64

Note: Pre/Post: pre- and post-training session, respectively (kicking without flippers). T1-T6: training sessions 1-6 (kicking with flippers).

Table II. Mean body wave velocity ( $\text{m} \cdot \text{s}^{-1}$ ), variability ( $s$ ), and effect size (ES), relative to the pre-training session, of the hip-knee, knee-ankle (knee-metatarsophalangeal for leg flipper condition), and velocity index over all experiment sessions for the leg flipper and foot flipper groups.

		Pre	T1	T2	T3	T4	T5	T6	Post
<b>Hip-knee</b>									
Leg flipper	Mean	-3.35	-4.24	-4.82	-4.88	-4.22	-4.42	-4.59	-3.34
	$s$	0.70	1.06	1.30	0.92	1.19	1.08	1.42	0.96
	ES		-1.28	-2.11	-2.20	-1.25	-1.54	-1.78	0.02
Foot flipper	Mean	-3.68	-3.28	-2.72	-3.23	-3.53	-3.44	-3.44	-3.51
	$s$	1.23	0.77	0.49	0.63	0.89	0.89	0.75	1.33
	ES		0.32	0.78	0.36	0.12	0.19	0.19	0.13
Control	Mean	-4.46							-3.79
	$s$	1.45							0.75
	ES								0.46
<b>Knee-ankle</b>									
Leg flipper	Mean	-2.82	-4.11	-4.20	-4.38	-4.21	-4.52	-4.39	-2.98
	$s$	0.50	1.22	1.18	1.70	1.14	1.64	1.46	0.31
	ES		-2.58	-2.76	-3.12	-2.78	-3.41	-3.13	-0.33
Foot flipper	Mean	-3.96	-4.09	-4.09	-4.51	-4.04	-4.22	-4.70	-3.86
	$s$	0.81	0.61	1.13	1.09	0.68	0.47	0.94	0.84
	ES		-0.17	-0.17	-0.68	-0.10	-0.33	-0.92	0.12
Control	Mean	-3.97							-3.84
	$s$	0.60							0.69
	ES								0.21
<b>Velocity index</b>									
Leg flipper	Mean	0.85	0.98	0.87	0.86	1.01	0.97	0.98	0.97
	$s$	0.13	0.18	0.16	0.16	0.24	0.17	0.23	0.30
	ES		0.96	0.11	0.02	1.19	0.87	0.94	0.86
Foot flipper	Mean	1.14	1.30	1.40	1.38	1.19	1.28	1.41	1.17
	$s$	0.27	0.32	0.56	0.38	0.25	0.35	0.30	0.32
	ES		0.58	0.97	0.91	0.19	0.53	0.99	0.12
Control	Mean	0.99							1.07
	$s$	0.40							0.39
	ES								0.21

Note: Pre/Post: pre- and post-training session, respectively (kicking without flippers). T1-T6: training sessions 1-6 (kicking with flippers).

Table III. Mean values, within-group variability ( $s$ ), and effect size (ES) of speed ( $\text{m} \cdot \text{s}^{-1}$ ) and kick frequency (Hz) over all sessions for the leg flipper and foot flipper groups.

		Pre	T1	T2	T3	T4	T5	T6	Post
<b>Speed</b>									
Leg flipper	Mean	0.72	0.82	0.91	0.86	0.86	0.86	0.84	0.70
	$s$	0.16	0.09	0.12	0.10	0.10	0.07	0.11	0.07
	ES		0.62	1.22	0.86	0.85	0.87	0.71	-0.14
Foot flipper	Mean	1.01	1.25	1.16	1.24	1.20	1.20	1.18	0.85
	$s$	0.07	0.13	0.11	0.15	0.17	0.15	0.13	0.12
	ES		3.56	2.21	3.40	2.81	2.75	2.57	-2.50
Control	Mean	1.06							0.99
	$s$	0.05							0.06
	ES								-1.47
<b>Kick frequency</b>									
Leg flipper	Mean	1.92	1.60	1.64	1.70	1.70	1.77	1.71	1.94
	$s$	0.24	0.13	0.21	0.30	0.22	0.18	0.36	0.33
	ES		-1.34	-1.18	-0.91	-0.91	-0.61	-0.88	0.06
Foot flipper	Mean	1.96	1.57	1.61	1.71	1.71	1.58	1.63	1.84
	$s$	0.19	0.22	0.22	0.30	0.26	0.25	0.46	0.35
	ES		-2.01	-1.81	-1.30	-1.29	-1.96	-1.71	-0.60
Control	Mean	2.21							2.12
	$s$	0.21							0.35
	ES								-0.43

Note: Pre/Post: pre- and post-training session, respectively (kicking without flippers). T1-T6: training sessions 1-6 (kicking with flippers).



speeds of the training sessions. The best speeds for the foot flipper group were achieved in T1.

Kick frequencies decreased greatly when using flippers. The average decrease of the stroke frequency during training for the foot flipper group was 16.8% of the pre-training value and 12.5% for the leg flipper group. When the constraint environment was returned to the barefoot condition in the post-training session, swimmers in both the leg flipper and foot flipper groups achieved kicking frequencies similar to those in the pre-training sessions.

There were no obvious trends with respect to within-group or within-swimmer variability across sessions.

## Discussion

In this study, adjustment to changes in task constraints, in particular the presence or absence of flippers in underwater flutter kicking in swimming, were investigated. The main indicators of whether the movement pattern remained appropriate for performance of the task were the percent power in the fundamental Fourier harmonic of the vertical undulations of the hips, knees, and ankles and the velocity index of the body wave.

Although decreases in percent power during training sessions were reflected in effect sizes up to 1.03 for both the leg flipper and foot flipper groups, the percentage of power in the first harmonic of the undulation of hip, knee, and ankle joints for both the leg flipper and foot flipper groups remained very high. Neither the leg flipper group nor the foot flipper group fell substantially below the mean values for skilled swimmers in the study conducted by Sanders (2007), being 97.7% for the hip, 97.2% for the knee, and 99.4% for the ankle. Thus, any effect on this indicator of suitability of movement pattern for the task was very small. Similarly, in the post-training trials the swimmers did not return to as high values as in the pre-training trials. However, given that a similar effect occurred in the control group, which did not have any change in the task constraints, and that the percentage of power in the first harmonic of all swimmers remained high, it can be concluded that any effects of change in task constraints on the sinusoidal nature of the task were very small.

Similar to the study of Sanders (2007), the ankle joint had the highest percentage of power in the first harmonic among the lower extremity joints in all groups in all conditions. On the basis that the mean percentage was greater than 99% under all conditions and that variability was very small, it may be concluded that the movement at the end of the segmental chain remained extremely smooth and rhythmical regardless of the changes in task

constraints and regardless of whether the task constraints were familiar or unfamiliar.

Appropriate Fourier phase characteristics of the vertical oscillations of the joints were indicated by the hip–knee and knee–ankle (knee–metatarsophalangeal joint for the leg flipper condition) body wave velocities and body wave velocity index across all sessions. Although there was a substantial change in wave velocities of the leg flipper group, the velocity index remained appropriate for task performance. When the swimmers returned to barefoot kicking, the body wave velocities and velocity indices for the foot flipper group returned very rapidly to values seen in the pre-training session.

Thus, the results indicated that the systems of swimmers adjusted within the first block of 10 trials to changes in task constraints by retaining the smoothness and phase characteristics of the vertical undulations known to be associated with efficient propulsion. Furthermore, the fact that the variability in the first block of trials was no greater than in subsequent blocks indicated that adjustment was almost immediate. This interpretation was confirmed by inspection of results of individual swimmers for the very early trials. The percent power in the fundamental movement frequency and the phase relationships among the segments were immediately appropriate and not different from subsequent trials. This indicated that performers can very rapidly reproduce the smooth sinusoidal movement pattern and appropriate sequencing of segmental contributions despite the change in constraints regardless of whether the constraints introduced were familiar or unfamiliar.

The results for kicking frequency indicated that although there were some slight variations in individual responses, swimmers adjusted their kicking frequencies immediately to a change in constraint conditions, both with the introduction of flippers and when returning to barefoot kicking. A slower kicking frequency in the flipper conditions than the barefoot condition was expected due to the increase in resistance to movement associated with increased surface area pushing against the water. To continue kicking at the same frequency as in the barefoot condition would require a very large increase in torque at the joints.

There appeared to be a natural tendency to vary the kicking frequency within and between the training sessions. This may indicate the system “exploring” the movement possibilities to optimize performance (Davids, Glazier, Araújo, & Bartlett, 2003). There were no obvious trends with respect to the within-participant variability across the sessions except that all three leg flipper participants had small variability in T1 relative to many other sessions. Given that the lowest variability occurred for the first

session of the unfamiliar constraint environment, this warrants further investigation of the coordination of the system. It may be, for example, that the system seeks to stabilize performance under the new conditions before exploring the movement possibilities to “fine tune” towards optimal performance.

Despite the very rapid adjustment to reproduce the appropriate movement pattern, performance in terms of speed was not optimal in the first block of trials following the introduction of the unfamiliar leg flippers. The lowest speeds for leg flippers during the training sessions were in T1 and the highest in T2. This indicates that some time was required to “fine tune” the scaling of the muscle synergies to optimize performance in the changed and unfamiliar constraint environment. The best speeds for the foot flipper group were achieved in the first block of trials (T1), indicating rapid rescaling of the parameters of the muscle synergies to adjust to the changed but familiar constraint environment.

The decrement in speed across the later training sessions and from post-training to pre-training was much larger for the foot flipper group than the leg flipper group. This is surprising given that the foot flipper group was accustomed to changing between the foot flipper and barefoot constraints. In view of the fact that the percent power in the fundamental harmonic and velocity index indicated that the movement pattern remained appropriate for the task, the decrement in speed must have been due to factors other than deterioration in the movement pattern or to loss of ability to optimize performance through effective scaling of the parameters of the muscle synergies. Such factors may be fatigue or loss of motivation. The fact that even the control group participants had a decrement in performance is further evidence for this possibility.

Rescaling parameters of the muscle synergies when changing to the unfamiliar constraints associated with the leg flippers enabled the system to optimize the interaction with the fluid environment – that is, efficient production of the reversed Karman vortex street (Lighthill, 1975), whereby the shedding of the vortices yields a propulsive reaction force (Beal et al., 2006; Colgate & Lynch, 2004; Triantafyllou et al., 2000). It is noteworthy that this exploration may have been inhibited in the first block of trials by the small variability in kicking frequency.

The results of this study have some implications for coaching practice. Assuming that the change in task constraints does not demand a change in the fundamental movement pattern, as may be the case if organismic constraints such as strength do not permit the use of the familiar movement pattern, then adjustment to familiar task constraints is very rapid. However, if the task constraints are unfamiliar,

some practice might be required to appropriately rescale the parameters of the muscle synergies.

In the specific example of swimming, this means that if a swimmer wishes to do some “over speed” work in the warm-up before a race by swimming with his or her usual flippers, the rescaling of the system to produce the appropriate kick without flippers from the beginning of the race would not be a problem. However, if a swimmer borrowed someone else’s flippers before the race, he or she should have a modest number of kicking cycles without flippers to rescale the muscle synergies before competing.

Although further work is required across a range of sports, the results of this study suggest that when constraints are unfamiliar, some time should be provided to athletes to adjust to unfamiliar task constraints before competing. For example, members of the school hockey or cricket team who may not have their own stick/bat may benefit from having several hits with the stick or bat that they will use in the game. This would ensure that they rescale the parameters of their muscle synergies before taking to the field to adjust to different mass and inertial characteristics of the implements. Similarly, when changing from a three iron to a wedge in golf, only a couple of practice swings may be required to rescale the muscle synergies between shots when a player is very familiar with his or her own clubs. However, if using a set of unfamiliar clubs, the player could benefit by having several more practice swings.

## Conclusion

The purpose of this study was to investigate the process of adjustment to change in task constraints. The task of prone underwater flutter kicking was selected because the characteristics of the movement pattern required for effective performance are known. Thus, the effect of familiarity on the rate of adjustment to task constraints could be assessed independently of the effect of the requirement for change in movement pattern. From this work it can be suggested that, in agreement with the first hypothesis, human systems can adjust very rapidly to both familiar and unfamiliar task constraints when the appropriate movement pattern has been established previously through practice. However, rapid adjustments to produce an appropriate movement response do not preclude continued improvement through further rescaling of the parameters of the muscle synergies to “fine tune” performance. The evidence from this study indicates that rescaling takes longer when the task constraints are unfamiliar than when they are familiar, supporting the second hypothesis. Therefore, coaches should ensure that practice includes all possible scenarios of task

constraints that athletes are likely to encounter in competition.

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