MOTOR CONTROL PATTERNS IN ELITE SWIMMERS' FREESTYLE STROKE DURING DRYLAND SWIMMING

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The purpose of this study was to compare motor control patterns of elite freestyle swimmers when asked to swim at 100m freestyle pace using a dryland swimbench. Collegiate and masters level swimmers (n=15) whose 100m freestyle time were faster than 75% of the FINA cutoff time, performed four 10 second trials of freestyle swimming on a dryland swimbench. 3-D kinematic analysis was used to calculate displacement in the hand in the cranial-caudal, vertical, and medial-lateral directions. A 2-way repeated measures ANOVA was used to compare hand path between swimmers and within trials (n=58). Data was not statically significant, but three distinct combinations of hand paths were used to perform the 100m freestyle task on the swimbench. These hand paths differed from historical in-water data. Findings imply individual swimmers adjusted kinematics on the swimbench to accommodate for environmental constraints.

KEY WORDS: biomechanics, dynamical systems.

INTRODUCTION: Traditional dynamical systems model explains the bilateral arm motion of freestyle swimming as coordinated structures emerging from the central nervous systems' (CNS) ability to control the redundant degrees of freedom of the shoulder, elbow and hand (Latash, 1998). Coaching for performance enhancement, using this model, means finding a generalized, optimal movement pattern and instructing all athletes to move in the same way. Schleihauf (1979) distinguished three variations of hand path used during the propulsive phase of freestyle swimming in elite swimmers: a medial-lateral path; a deep catch with a straight line pull, and a primarily medial hand path. This implies individual swimmers vary motor control patterns to accomplish the task of swimming freestyle.

The contemporary dynamical systems model (Davids et al., 2003) suggests that environmental, task, and anthropometric constraints contribute to the evolution of movement patterns. Spontaneous pattern reorganization occurs from continuous sensory feedback from the CNS allowing athletes to develop individual movement strategies based on the surrounding constraints. This version of dynamical systems provides an explanation for the variation in elite swimmers' freestyle stroke reported by Schleihauf (1979). Based on this, it would be expected that freestyle stroke technique in elite swimmers when swimming freestyle on a dryland swimbench will also vary among swimmers. Swimbenches are land based training devises that allow swimmers to mimic swimming motions lying prone and using a pulley system. Evidence of stroke technique differences would provide valuable information for coaches trying to enhance swimming performance through correction of stroke technique, possibly coaching each swimmer from a more individualized standpoint. The purpose of this research was to determine if different motor control patterns can be seen among elite swimmers performing simulated 100m freestyle on a dryland swimbench.

METHODS: Data Collection: A sample of 15 elite healthy collegiate and masters' swimmers volunteered to participate in this study (8 males, age=24.7±8.0yrs, height=183.8±4.0cm, mass=78.4±7.0 kg; 7 females, age= 26.0±11.0 yrs, height 170.2± 6.0 cm, mass 64.8± 5.6 kg). Written informed consent was obtained from each participant prior to implementing the study, which was approved by the university's human participant institutional review board. All participants' 100m freestyle times were equal to or greater than 75% FINA national cutoff time.

Freestyle strokes were performed on a swimbench (Swimworks, Inc, Santa Rosa, CA) which allowed kicking and rotation of the trunk about the cranial-caudal axis. Following a 30-minute familiarization session, 30 reflective markers were attached on the upper extremity and torso of the swimmer. Each swimmer performed four ten second trials of freestyle swimming on the swimbench at a 100 m sprint race pace, with each trial separated by 2 seconds with the participant adopting a streamlined position to simulate the aspects of the flip-turn. Kinematic data were collected at 200 Hz using EVaRT 5.0 (Motion Analysis Corporation, Santa Rosa, CA).
Data were analyzed in Matlab 7.1 (The Mathworks, Inc, Natick, MA). Using an interactive algorithm, three phases of the stroke were defined: pull; push, and recovery. In absence of the water surface, the origin was set to the height of the seventh cervical vertebrae (C7) marker for the first five frames of the streamlined position before trial 1. Data were smoothed using a low pass Butterworth filter with cutoff frequencies, determined via residual analysis (Winter, 2005), of 4 Hz for the shoulder, elbow, and hand, and 2 Hz for the trunk. Dependent variables were range of hand displacement in the cranial-caudal (H_d^{cc}), medial-lateral (H_d^{ml}) and vertical (H_d^{v}) directions.

Data Analysis: Hand displacements(m) for all swimmers (n=15) were analyzed using a 2 way repeated measures ANOVA (Version 12.0; SPSS, Inc, Chicago. IL). Hand displacements(m) were also graphed for the complete stroke cycle, with all trials overlaid (n=58) and visually inspected for variability in stroke patterns.

RESULTS: Means and standard deviations of hand displacement(m) for four trials on the swimbench in the cranial-caudal, medial-lateral and vertical directions are shown in Table 1. No significant differences were found among swimmers and trials ($p > 0.05$).

Table 1. Average Left and Right Hand Displacements (m) in the Cranial-Caudal (H_d^{cc}), Medial-Lateral (H_d^{ml}) and Vertical (H_d^{v}) Directions for Elite Swimmers (n=15) Performing Four Trials of Freestyle Swimming on a Dryland Swimbench

		Trial 1	Trial 2	Trial 3	Trial 4
H_d^{cc} (m)	Right	1.0±0.15	0.94±0.23	1.01±0.19	0.92±0.20
	Left	1.0±0.18	0.98±0.19	0.99±0.19	0.97± 0.17
H_d^{ml} (m)	Right	0.30±0.17	0.30±0.10	0.32±0.07	0.33±0.10
	Left	0.32±0.13	0.32±0.11	0.31±0.09	0.33±0.13
H_d^{v} (m)	Right	0.44±0.16	0.41±0.19	0.45±0.23	0.44±0.17
	Left	0.36±0.12	0.39±0.17	0.39±0.19	0.39±0.17

Elite swimmers had similar displacement values; however three slightly different combinations of hand path in the cranial-caudal, medial-lateral and vertical directions were adopted by swimmers within trials and among swimmers. Figure 1 (left side) is a representation of three distinct hand paths used by elite swimmers on the swimbench in the cranial-caudal versus vertical direction. The solid line shows a longer stroke where the hand extended cranially from the starting position, reaching maximum vertical displacement (-0.6m) at 0.4m cranial to C7 then steadily moved upwards toward C7. The dash-dot line is a shorter, shallower hand path. The hand reached maximal vertical displacement (-0.4m) at 0.5m cranial to C7 and remained at that depth from approximately 0.5m cranial to 0.2m caudal of C7, when upward movement toward C7 began. The dotted line shows an overall shallower, flatter hand path that reached maximum vertical hand displacement at 0.2m cranial to C7, then gradually moved upward till 0.6m caudal of C7. Figure 1 (right side) is a representation of hand motion in the cranial-caudal versus medial-lateral directions. The solid line shows the hand moved laterally for the first 0.1m of pull and then followed a medial path for the remainder of the stroke. The dashed line shows the hand extended to maximum range of cranial hand displacement (0.6m) and followed a slightly curved path between -0.2m and -0.4m lateral of C7. The dotted line shows a wider lateral arm path, 0.4m lateral to C7 from maximum cranial to caudal displacement (0.6m to -0.6 m).

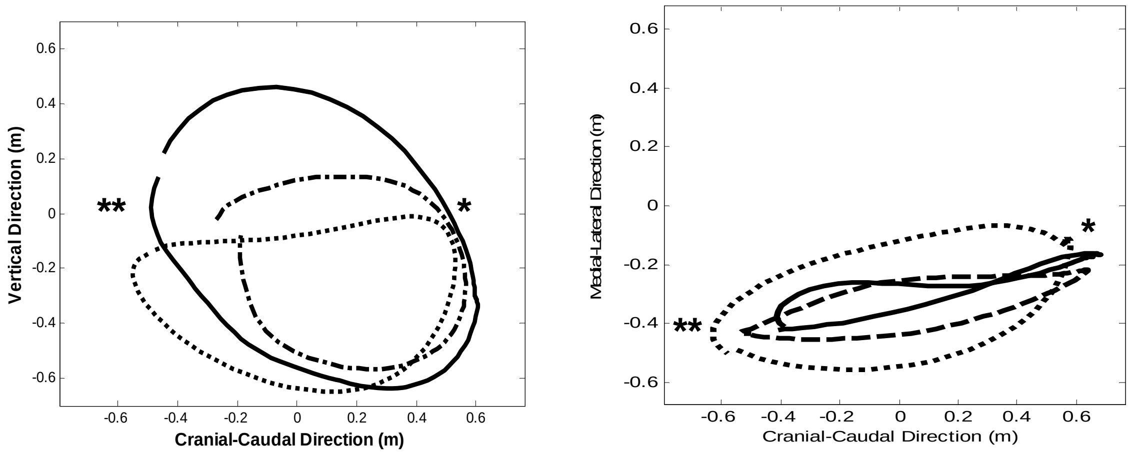

Figure 1: Three primary hand paths used by elite swimmers (n=15) for freestyle swimming in cranial-caudal vs. vertical directions (left), and in the cranial-caudal vs. medial-lateral directions (right) on a dryland swimbench. The hand paths are not exclusive as different combinations of hand paths in the cranial-caudal vs. vertical directions where seen with different combinations of hand paths in the medial-lateral direction between swimmers.
Note: * beginning of the propulsive phase; ** end of the propulsive phase.

DISCUSSION: Elite swimmers had similar ranges of hand displacement during the propulsive phase on a dryland swimbench with standard deviations between 0.1 and 0.2 m. Elite swimmers also displayed three distinct combinations of hand paths during freestyle swimming on a dryland swimbench. The data agrees with previous research reported for in-water swimming by Schleihauf (1979), describing variation in propulsive phase stroke technique among elite swimmers. The present data indicates each individual elite swimmer made different kinematic adjustments to their freestyle swimming when the environmental and task constraints were varied. Hand paths on the swimbench were different to published in-water hand paths indicating swimmers changed hand patterns to swim freestyle.

Dynamical systems theory suggests that the CNS spontaneously reorganizes movements as sensory feedback is received from surrounding constraints (Davids et al., 2003). Researchers agree freestyle swimming technique is integral to peek performance, but that elite swimmers demonstrate differences in stroke styles (Schleihauf, 1979, Seifert et al., 2007). On the swimbench, variations of hand path could be seen during the propulsive phase. Stroke technique variations within trials suggest spontaneous reorganization of the CNS from the task constraints (Davids et al., 2003). Swimbenches use a pulley system where swimmers place their hands in paddles to simulate water resistance. Paddles constrain the movement of the hands to the length of the pulleys. In water, the hand, elbow and shoulder are free to move through all planes of motion which allows swimmers to optimize the forces in the aquatic environment. On the swimbench, swimmers had fewer degrees of freedom at the distal segment (hand attached to paddle), but still adjusted the length and depth of the hand path to compensate for this constraint and to achieve the task. Changing hand paths required the swimmer to readjust shoulder flexion and abduction angles, and elbow flexion angles, while controlling the hand paddle in the pulley system. As each trial lasted 10 seconds, and swimmers performed between seven to eleven strokes in each trial, it is plausible that the variability seen among swimmers is an example of dynamical reorganization of the CNS to accomplish a goal-oriented task.

Data were compared with the three stroke techniques of in-water freestyle swimming described by Schleihauf (1979). In general, on the swimbench, all swimmers used a flatter, more lateral to medial hand path most likely due to differences in the environmental constraints (Schleihauf, 1979). Swimmers were instructed to swim using their 100m freestyle sprint pace. In the water, swimmers receive sensory feedback from the interaction of the hand and forearm with the water during a pulling motion. During a sprint race, swimmers make modifications to their stroke based on how much resistance they feel as they press through the water, pressing harder to increase velocity (Seifert et al., 2007). On the swimbench, sensory feedback was primarily received from the hand paddles, so swimmers adapted their freestyle technique to exploit this feedback. First, swimmers used a shallow hand path as they moved in the cranial-caudal direction. To generate momentum on the swimbench, the swimmer pulls with the hand flat against the paddle. Flexion at both the elbow and the wrist would enable the swimmer to maximize contact of the hand on the paddle, but this would also decrease the downward depth of the pull creating a shallower path of motion. Second, instead of a sculling motion, swimmers moved the hand from a medial to lateral direction until the end of the propulsive phase. Lateral movement of the hand may have been the swimmers' strategies to engage the latissimus dorsi muscle for power as the arm moved cranial to caudal, as this is the primary function of the muscle.
The ability of the elite swimmers to adjust freestyle stroke technique to the task and environmental constraints supports the idea that the CNS can spontaneously reorganize based on feedback during a goal driven task (Davids et al., 2003). The variations in freestyle motion in this sample of elite swimmers imply the use of a swimbench allows for subtle individual variation of motion.

CONCLUSION: On a dryland swimbench, elite swimmers appeared to utilize slightly different movement patterns. This suggests elite level swimmers are able to spontaneously reorganize freestyle propulsive phase movement patterns based on environmental and task constraints. Thus coaches should be aware of this inherent variation in swimmers stroke technique and provide individually based feedback.

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