The Fundamentals behind Curvilinear Vs Straight Line Pull

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Abstract

This study carried out five experiments to validate Counsilman's explanation of elite swimmers' tendency to move their hands in curvilinear patterns (zigzags) rather than use 'straight line' pulling. The findings show beyond reasonable doubt that Counsilman's reasoning of "once it (water) started moving will offer less traction and when moved away from the moving water will allowed the paddle (hand) to find "still water" for traction", was valid, and indicate that further investigation would be warranted.

Introduction

In the early 20th century, a set of 5 questions on how crawl strokes should be swam, was sent to sixteen leading swimming experts in America. Their replies were reported in the Intercollegiate Swimming Guide and in Speed Swimming [6] entitled, "Symposium on the crawl stroke". In one of the questions, "What, in your judgment, is the best form in the arm stroke regarding "reach," "catch," and "pull through the water?" ten out of the eleven swimming experts mentioned a "straight line pull" or advised avoiding a "Zigzag pattern". These interpretations were in line with Newton's third law concerning action and reaction where swimmers apply forces directly backwards in order to move forwards. One reply, from Lionel B. Mackenzie, coach of Swimming College of the City of New York, differed from the rest was. He said, "The pull or stroke through the water should be downward, until the hand is below the body, then swerving inward in a described arc finishing fully extended at the side of the body. The describing of the arc inward or under the body called for a slight bend of the arm at the elbow."

This inwards arc pattern below the body (akin to an inverted question mark) clearly contradicted Newton's law of action reaction, and due to this reason, I believe that Mackenzie's "valuable" recommendations at that time were largely ignored. And so the fundamental interpretation of stroke mechanics based on Newton's Third Law of Motion, (Straight line pull) dominated in the next half of the century.

When Counsilman observed his best swimmers using the curvilinear pathway this contradicted his understanding of stroke mechanics (straight line pulls), and he re-educated himself using fundamental fluid mechanics to find the answer. In 1977, Counsilman [5] presented his reasons why top swimmers move their arms in Zigzag (curvilinear) movements. He explained that once the water was started backward by the hand in a straight-line pull, the hand could no longer find any traction (propulsive force) from the moving water that was already going backward. He then introduced the term "still water" and explained that paddles (hands) must pushed against still water or water going in the opposite direction in order to get traction and create propulsion. He reasoned that the zigzag (curvilinear) movement of the hand allowed swimmers to get away from water that was already going backwards and work with still water to get traction (propulsive force). It is this (why swimmers move their arm in Zigzag movement) shift in fundamental understanding of stroke mechanics that led him to propose Bernoulli's principle of "lift" (Note: it is not the intention of this article to discuss or draw any conclusion on Counsilman's interpretation of Bernoulli's theory, but to examine his underlying reasons leading to his concurrence of the theory).

In 1979, Wood [9] studied a hand and forearm (model) using a wind tunnel, finding, "The hand must move through the water to create the pressure differentials necessary for force generation... It is an oversimplification to speak of the hand pushing water backward or searching for still water...".

Brent S. Rushall et al [2] using a caterpillar paddle-wheel analogy, reasoned that the general understanding of swimmers pushing directly backward was inefficient because the premise that the hand will be working in moving water was invalid. Both Wood's and Rushall's reasoning seemed to invalidate or contradict Counsilman's underlying reasoning. Although Counsilman, Wood and Rushall used sound reasoning, drawings, swimmers' strokes and wind tunnel experiments to support their points, none had attempted any experiment to validate their reasoning.

The intention of this article is to investigate and validate Counsilman's underlying reasons (zigzag movement of the hand allow swimmers to get away from water that is already going backwards and work with still water to get traction/propulsive force) which we still observe (curvilinear) in our swimmers today.

Method

In our first two experiments, we simulated a hand moving towards a floating leaf suspended in water (Figure 1) and a fast backstroke kick towards a plastic cone suspended in water (Figure 2). In the third and fourth experiments, we simulated a straight pull underwater using a flat board (paddle) representing a swimmer's hand (Figure 3), and, using the same board, we simulated a straight pull at the surface representing a "boat paddle" used to paddle the water in order for the boat to move forward (Figure 4). For the fifth experiment, with the same board we simulated a curvy pull pattern at the surface. Each experiment was repeated more than a dozen times.

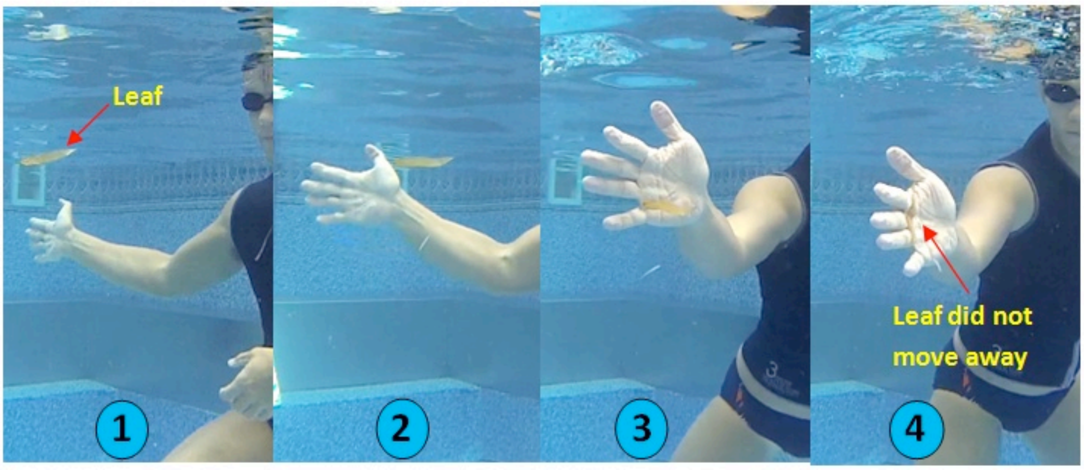

Figure 1 – Hand moves towards the leaf, but the leaf did not move

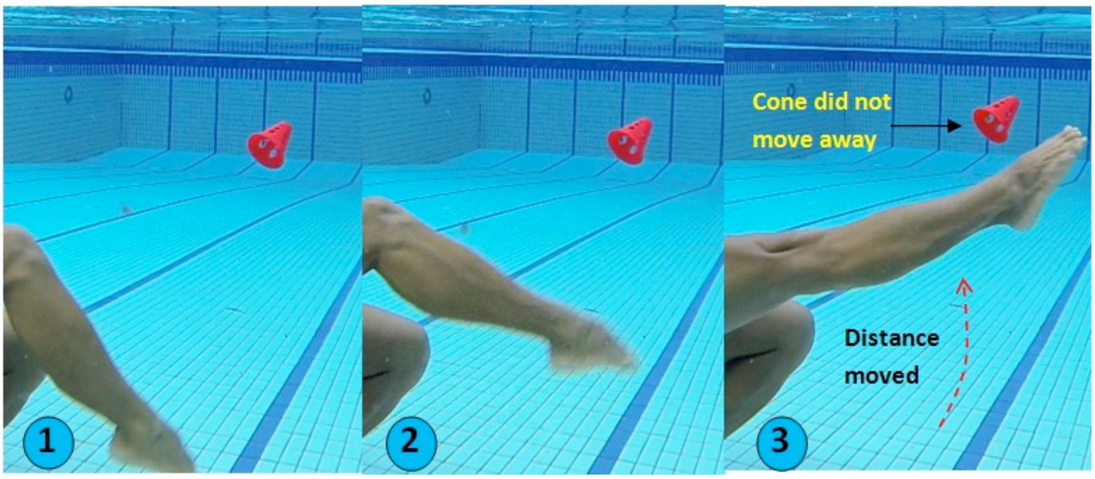

Figure 2 – Kick towards the red cone, but the cone did not move away

From experiments one and two (Figure 1 and 2), we observed that when forces were applied towards the floating objects (leaf and cone), neither object was affected by the forces.

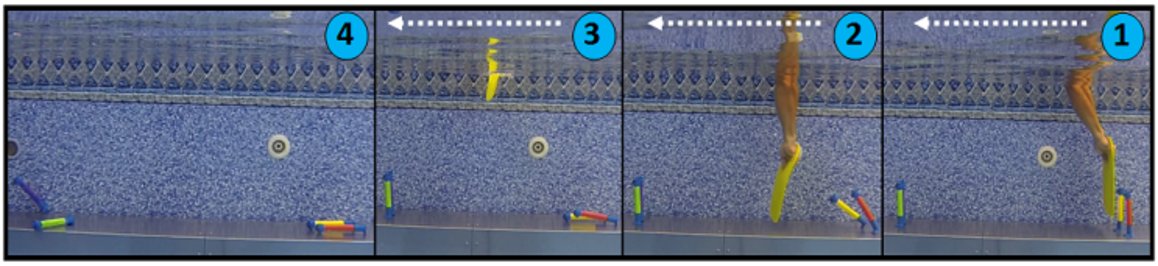

Figure 3 - Simulating an underwater Paddle (hand) in a straight line pull from right to left

Figure 3, picture 1 shows the insertion of the board (paddle) into the water. Picture 2 shows the two sticks (red and yellow) falling towards the moving paddle when it is moved from right to left. Picture 3 shows the two sticks (red and yellow) falling completely onto the floor after the paddle is completely lifted from the water. Picture 4 shows the remaining two sticks (green and purple) falling in the same direction as the red and yellow sticks within 2 seconds after the board is lifted from the water.

Figure 4, shows the straight pull of the "boat paddle" producing two rotating mass of water (vortexes) at the back (near the edge) of the moving boat paddle. When the boat paddle was lifted out of the water the two vortexes continued their movement (See the dotted yellow arrow at the bottom) in the same direction as the "boat paddle".

In the fifth experiment, (Figure 5) using the same yellow board (paddle) as experiment 3, we simulated a curvy hand movement. We observed that the initial sideways movement produced two rotating mass of water (vortexes). When the board moved inwards (See 'side view'), the edge of the board (facing the viewer) moved away from the vortex and a new vortex formed at the same edge of the paddle. When the paddle was lifted, we observed the rotating mass of water (vortexes) continuing its movement in the same direction as the board.

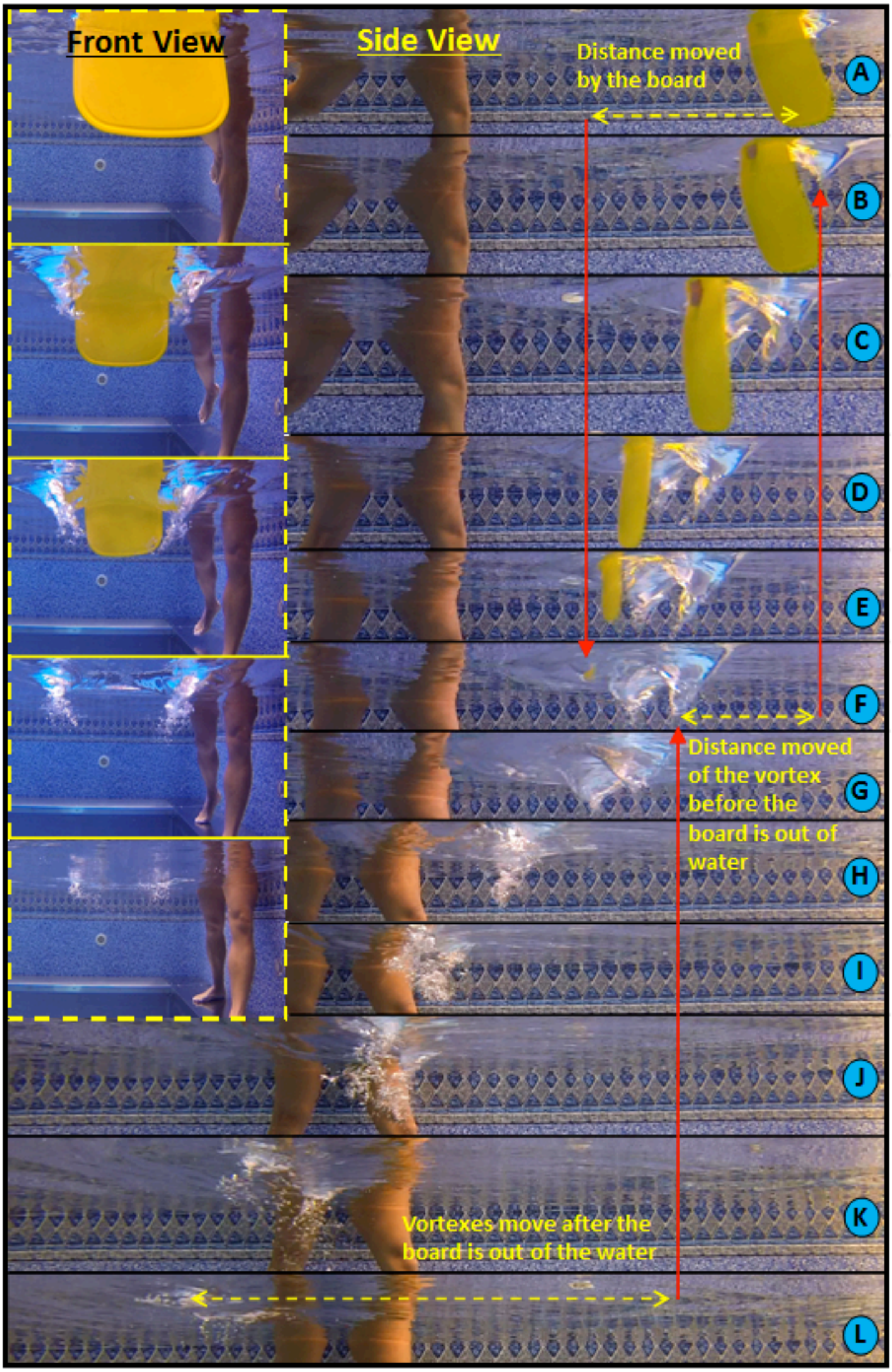

Figure 4 – Simulating a “Boat Paddle” in a straight pull

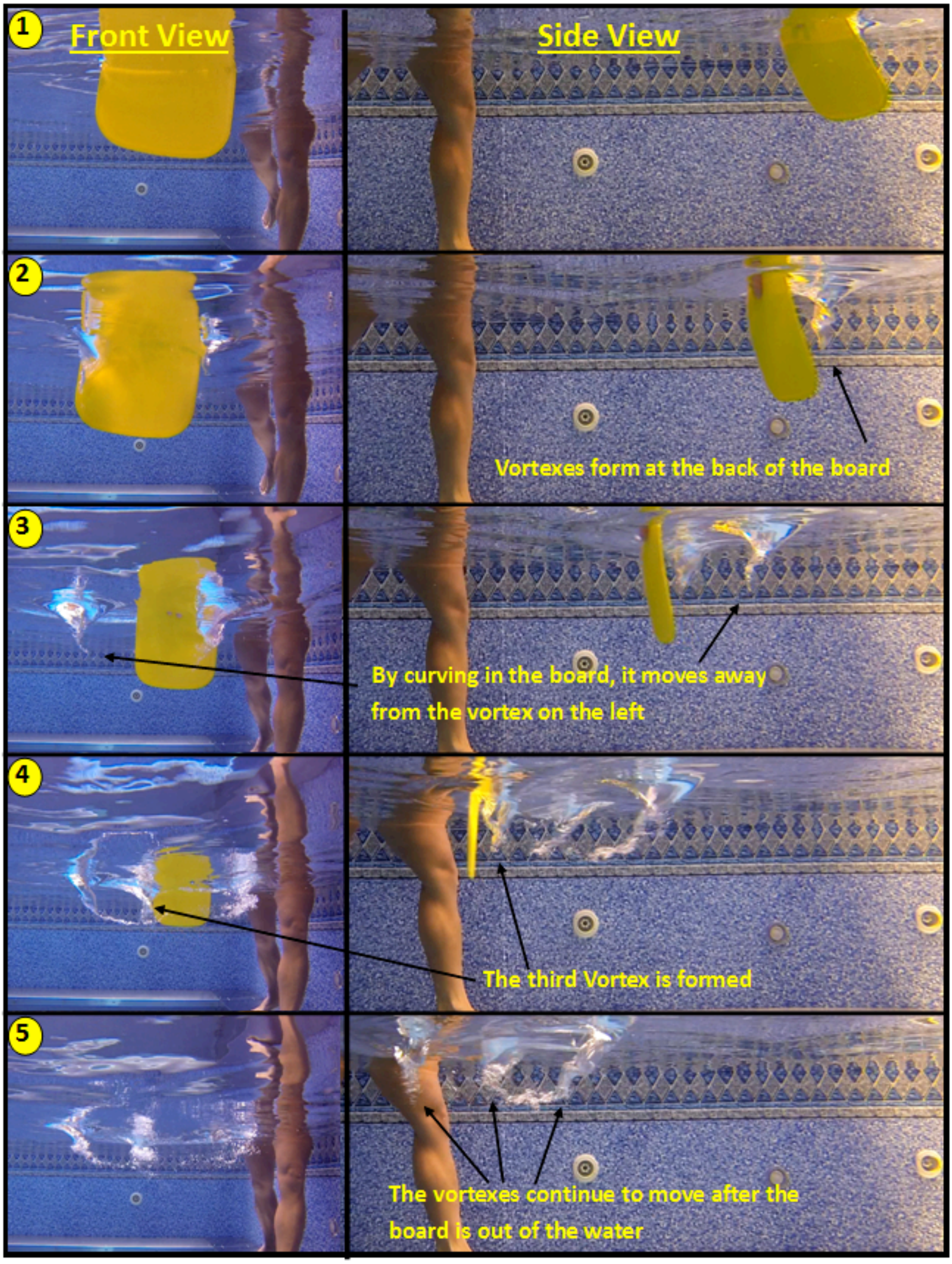

Figure 5 – Simulating a curvy pull pattern

Findings and Discussion

1) With reference to Figure 1 and 2, we deduced that when swimmers apply forces in water, the water pushed by the hand (palm facing) and feet did not seem to start moving the water backward, otherwise we should see the leaf and cone moving away.

2) Referring to Figure 3, using a paddle (hand) in a straight line pull, we deduced that the water had moved backwards (as shown in picture 4) when both sticks (green and purple) fell after the paddle was lifted in mid-way.

3) Using the same paddle (hand) to simulate a boat paddling forward (See Figure 4), we deduced from the two rotating mass of water that it had continued to move backwards even after the paddle was lifted up. Therefore, one would rationalise that it will require less effort to continue moving the two rotating masses of moving water. As a simple example; when one pushes a stationary car, once the car started to roll forward, one would use less energy to keep the car rolling at the same speed. A point to note, the location of the moving water as shown in Figure 4 is located at the back face of the moving paddle (dorsal side of a moving hand). This observation of double rotating masses of water were also mentioned in the fluid mechanics book by Alexander Smits [1], where he observed the rotating mass of water when moving a board through water.

4) Simulation of the curvy hand patterns (Figure 5) showed an additional rotating mass of water being formed. We deduced the curvy movements allowed the paddle (hand) to move away from the path of one moving rotating mass of water to generate a third one, and together with the other two vortices, continued to move towards the back even after the board was lifted.

The following context is not intended to show the theory of swim propulsion or discuss the theory of fluid movement but to use observation from the experiments to validate Counsilman's reasoning (still water) and whether it warrants further investigation.

With reference to Counsilman's finding of "still water": Figures 4 and 5, show that the moving paddle (hand) had indeed moved water backwards. However the water was being moved from the BACK and not from the front (Figure 1 and 2). Hence, regardless of whether one is pulling straight line or in a Zigzag pattern (curvilinear), the hand (front) would face "still water". In this case, I believe that finding of "still water" should look for at the back of the hand and not at the front. Indeed, once the water was started backwards by the hand in a straight-line pull, the hand would find less traction (propulsive force) from that moving water that was already going backward.

In Wood's findings [9], he stated, "...for force generation, it is oversimplification to speak of the hand pushing water backward or searching for still water...". However, from these experiments, I believe Counsilman's explanation for his champion swimmers' zigzag hand pattern (curvilinear) and finding of still water to be "valid" (from observation of Figure 4 and 5). When the paddle moved away from the momentum of water that was already moving, it allowed the back of the paddle to find "still water" to generate another rotating mass of water backwards, hence I deduce it would increase the propulsive force.

This "still water" term is also used by Schleihauf [8] and Sanders [7] in their articles to suggest that the finding of still water would allow force generation. Schleihauf [8], described Mark Spitz' changes in hand direction as keeping the hand working in still water. Sanders [7] mentioned, "... a possible advantage of using sculling motions is that the hand continually "finds still water"... , but when the hand direction is constant, water starts to move with the hand and reduces force". (Note: the author of this article does not have any intention to draw any conclusion to the above mentioned authors' research.)

Summary

I believe that the five experiments described in this article supported and show beyond reasonable doubt Counsilman's reasoning of the water – "*once it started moving will offer less traction and when moved away from the moving water will allowed the paddle (hand) to find "still water" for traction"*. Further investigation and studies could be conducted to further increase our understandings on the fundamentals of swim propulsion.

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