COORDINATION ABILITIES IN YOUNG SWIMMERS AS THE IMPORTANT FACTOR OF FUTURE SUCCESS IN WORLD CHAMPIONSHIPS

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Abstract: *Coordination abilities in swimming—specifically the timing and interaction of arm strokes—may be a decisive factor in determining which young athletes eventually excel at the elite level. This theoretical paper proposes that early development of advanced stroke coordination patterns (such as overlapping arm propulsion with minimal glide) strongly correlates with greater success in later international competitions. We review current research on front crawl coordination and performance, develop a framework linking early coordination skills to long-term competitive outcomes, and discuss supportive findings. Key studies show that as swimmers increase speed, they transition from a catch-up style stroke to a superposition (overlap) mode, and that elite swimmers maintain more stable intracyclic velocity than novices. We further incorporate new data visualizations of training interventions that improved young swimmers' stroke length and inter-limb coordination. These insights collectively suggest that coaching practices focusing on coordination development in youth could enhance the likelihood of future championship success.*

Keywords: *swimming coordination, youth athletes, stroke index, intracyclic velocity variation, performance prediction, motor learning*

Introduction

Success in competitive swimming is determined not only by strength and endurance but also by technique and coordination. In young swimmers, efficient stroke mechanics can play a pivotal role in laying the foundation for elite performance later in life. Among technical factors, inter-limb coordination (the way the arms are synchronized during the stroke cycle) is believed to influence a swimmer's speed and efficiency. For example, a poorly coordinated stroke with long pauses (glides) between arm pulls can cause speed fluctuations and wasted energy, whereas a well-coordinated stroke maintains continuous propulsion and steadier velocity [2]. Many world-class swimmers exhibit a stroke pattern where one arm begins pulling before the other finishes (an overlapping or "superposition" stroke), eliminating dead spots in propulsion. This pattern contrasts with a "catch-up" style often seen in less experienced swimmers, where one arm waits for the other, creating a glide phase in each cycle.

Recognizing the potential importance of coordination, coaches and scientists have developed metrics to quantify it. Chollet's **Index of Coordination (IdC)** is one such measure, defined by the lag or overlap between the propulsive phases of the two arms. An IdC > 0% indicates a gap (catch-up), IdC = 0% means one arm starts as the other finishes (in-phase), and IdC < 0% denotes overlap of propulsive phases (superposition). As swimmers improve and swim faster, IdC typically decreases from positive toward zero or negative, meaning they reduce glide and increase overlap. The ability to adopt an overlapping propulsion pattern at high speeds is often observed in elite swimmers and is considered biomechanically advantageous. It minimizes intracyclic velocity variation (the speeding up and slowing down within each stroke) and can improve efficiency by avoiding needless drag from deceleration [2].

Given these considerations, this paper explores the hypothesis that **early development of stroke coordination patterns similar to those of elite swimmers (i.e. superposition of arm strokes with minimal glide) is a key predictor of future success in world-class competitions**. We aim to establish a theoretical framework linking young swimmers' coordination abilities with their long-term performance trajectory. The following sections review relevant literature, present a theoretical analysis of how early coordination skill might confer competitive advantages, and discuss findings including new illustrative data. Ultimately, we seek to provide coaches and talent scouts with insight into why and how to prioritize coordination in youth swimming training programs.

Literature Review

Recent research has shed light on how coordination affects swimming performance and how it differs between skill levels:

- **Arm Coordination Regimes (Carmigniani et al., 2020):** Carmigniani and colleagues identified three distinct coordination regimes in front-crawl swimming across increasing velocities. At low speeds, even highly trained swimmers used an alternated "catch-up" style with noticeable gliding pauses between arm pulls. This coordination remained constant up to a first critical speed. Beyond that threshold, the glide time shortened with further speed increases, and above a second critical velocity the gliding pauses disappeared entirely as swimmers switched to a fully overlapping arm stroke. In other words, elite swimmers naturally transition from a glide-intensive stroke to a continuous propulsion stroke as they swim faster. The authors theorized that below the first critical speed, swimmers increase velocity by pushing harder in each stroke while keeping their timing unchanged, whereas above that speed they already use maximum force and thus must adjust timing (reducing recovery time and overlap strokes) to gain more speed. This finding underscores that proficient coordination (specifically, the ability to superpose arm propulsions) is an essential adaptation at high velocities.

- **Intracyclic Velocity Variation and Skill Level (Matsuda et al., 2014):** Matsuda and coworkers investigated whether elite swimmers exhibit more stable velocity within each stroke than beginners, and if arm coordination explained any differences. They found that **intracyclic velocity variation (IVV)** was significantly lower in elite swimmers – about 26% less fluctuation – compared to novice swimmers, at all tested speeds. For instance, the elite group's IVV was roughly 7.3% (±1.3) while the beginners' was around 9.8% (±1.7), meaning the novices' speed rose and fell more within every stroke cycle. Such larger fluctuations can increase drag and energy cost, making the stroke less efficient [2]. Interestingly, the study noted that the **Index of Coordination (IdC)** did **not** significantly differ between the elite and beginner groups – both groups had similar arm timing patterns at equivalent relative speeds. This suggests that simply having an overlapping stroke timing (as measured by IdC) was not the distinguishing factor between these swimmers; rather, the elites were better at maintaining consistent propulsion and minimizing speed variations through other technique factors. The authors concluded that reducing IVV is essential for high performance [2], even if arm timing (IdC) alone doesn't separate elites from novices. In sum, elite swimmers likely coordinate their movements in a more refined way (beyond what basic IdC captures) to achieve a smoother, more economical stroke.

- **Effect of Assisted Speed on Coordination (Moriyama et al., 2024):** A recent study by Moriyama et al. examined whether forcing swimmers to go faster via assisted towing would alter their stroke coordination patterns. Fourteen collegiate swimmers performed 25 m front crawl trials under normal conditions and while being lightly towed (assisted) at slow, moderate, and maximal efforts [3]. As expected, towing increased velocity and stroke length (since swimmers could go faster with aid). Crucially, however, the **stroke coordination index (IdC)** responded primarily to the effort level and not to the presence of towing. In both assisted and normal swimming, when effort intensity rose, stroke frequency increased and IdC decreased (indicating more overlap in arm strokes at higher effort [3]. There was no significant difference in coordination between assisted and free swimming conditionsfile-fdx4fjpc3zqcz3aejmrv1n. In other words, **assisting the swimmers to go faster did not fundamentally change how they timed their arms**. The IdC changes were driven by the swimmers' own pacing—at higher exertion they naturally reduced glide, just as they would without towing. This finding reinforces the idea that coordination patterns are an intrinsic skill that swimmers carry with them; simply increasing speed externally doesn't magically improve or degrade coordination. It also implies that a swimmer's coordination tendencies (catch-up vs overlap) are robust traits at a given effort, and training, not just speed, is needed to alter those patterns.

Overall, the literature indicates that (1) elite performance involves adapting one's coordination to enable continuous propulsion at race speeds, (2) better swimmers achieve more consistent intracyclic speed (lower IVV) which is linked to efficiency[2], and (3) coordination style is a stable characteristic of swimmers that must be developed through practice rather than expecting it to change automatically with speed[3]. These insights set the stage for our theoretical analysis of why early coordination ability is so critical for long-term success.

Theoretical Analysis

Building on the findings above, we propose a theoretical framework wherein early **stroke coordination abilities** serve as a foundation for a swimmer's competitive development. The core hypothesis is that a young swimmer who can quickly adopt and refine an elite-like coordination pattern will have a higher ceiling for performance growth and a greater likelihood of reaching world-class times. Several factors support this hypothesis:

1. Continuous Propulsion Yields Competitive Speed Advantages: At high levels of competition (e.g. world championships), races are often decided by fractions of a second. A stroke that maintains continuous propulsion can give a swimmer a critical edge. If a young swimmer learns to eliminate gliding pauses and overlap their arm strokes effectively, they can keep their velocity more constant, avoiding the slowdowns that plague less coordinated swimmers. The theoretical benefit is twofold: higher average speed and improved efficiency. According to Carmigniani et al. (2020), once swimmers pass a certain speed, they must overlap arm pushes to go faster. Those who cannot make this coordination transition will plateau in speed, whereas those who can overlap smoothly can continue to increase velocity by increasing stroke rate without losing propulsion. Early mastery of an overlapping (superposition) stroke could therefore allow a young swimmer to reach and sustain velocities that others with a pronounced catch-up style cannot achieve until much later, if ever.

2. Improved Efficiency and Endurance through Lower IVV: A stable, well-coordinated stroke minimizes intracyclic velocity variation. As Matsuda et al. noted, less fluctuation in speed reduces wasted energy and drag[2]. Over the course of a race, especially longer events, a swimmer who maintains a steadier velocity will expend energy more economically. This means they can either swim faster for the same energy cost or last longer at a given speed. A young swimmer with inherently low IVV (due to good stroke control and coordination) is likely to have better endurance and efficiency, attributes that bode well for intense training and competitions. In theory, such swimmers can handle higher training loads with lower fatigue because their technique makes them energy-efficient. This could accelerate their improvement compared to peers who have technical inefficiencies. Moreover, **lessening IVV is essential to achieve high performance** as pointed out in prior [2]. Therefore, identifying youth swimmers who naturally exhibit low IVV or teaching them to achieve it via coordination drills might be a predictor of their capacity to perform at elite levels.

3. Early Coordination Skill as an Indicator of Neuromuscular Talent: The ability to coordinate complex movements is partly neuromuscular. Young swimmers who quickly learn the fine timing of a high-level front crawl stroke may simply possess a more advanced neural control of their muscles. This could correlate with other athletic attributes like better proprioception, timing, and adaptability. Such athletes might also pick up other techniques faster (starts, turns, underwaters) and respond better to technical coaching. Hence, early coordination prowess could be a marker of overall swimming talent. It might not be coincidence that many champions are described as having "natural feel for the water" or exceptional technique even at young ages. These observations align with the idea that talent identification should include technical skill assessments alongside physical tests. A swimmer who is very coordinated at age 12, for example, might be more likely to become a successful 18-year-old racer than a less coordinated peer who is equally strong and fit. Our framework thus treats coordination ability as part of the **talent DNA** of a swimmer.

4. Long-Term Development and Injury Prevention: There is also a long-term perspective: swimmers who utilize proper coordination likely place less strain on their shoulders and body because forces are distributed more smoothly. A choppy, uncoordinated stroke with big speed fluctuations can impart higher peak forces on the body (starting and stopping motion repetitively) and may contribute to overuse injuries or earlier burnout. In contrast, a fluid, well-timed stroke is not only faster but gentler in terms of force application. From a theoretical standpoint, young swimmers who develop coordinated strokes early might enjoy more sustainable training with fewer injuries, allowing them to train consistently over years — a key to reaching world-class performance. This factor indirectly contributes to future success: an athlete who avoids injury and ingrains efficient motor patterns will likely outperform one who struggles with technical flaws and frequent shoulder issues.

5. Adaptability to Race Demands: In high-level races, swimmers need to be tactically versatile – for instance, accelerating in the final lap of a 400 m or maintaining speed under fatigue. A swimmer with advanced coordination skills has a larger "gearbox" of technique. They can ramp up stroke rate and intensity while still keeping strokes efficient (overlap intact) as needed, much like experienced elite swimmers do [3]. A less coordinated swimmer might fall apart technically when attempting a late-race surge (e.g., stroke becomes short or timing goes off). Therefore, early mastery of coordination gives a competitive edge in race situations that demand a change in speed or strategy. It provides the swimmer with the ability to swim fast when it counts, without losing form.

Combining these points, we theorize a causal chain: **Young swimmers with superior coordination → more efficient and faster swimming in youth competitions → accelerated improvement and confidence → greater success in senior national/international competitions.** The relationship is likely mediated by the ability to train effectively (due to efficiency and fewer injuries) and to execute race strategies that leverage technical prowess. This framework is illustrated by the evidence that elite swimmers universally exhibit overlapping strokes at top speed, whereas those who cannot overlap effectively are rarely able to attain world-class times in sprint freestyle. While exceptions exist (some events or individuals may succeed with idiosyncratic technique), the general trend supports coordination as a cornerstone of performance.

It is important to note that coordination is not the *only* factor for success—endurance, strength, mental tenacity, etc., all matter. However, coordination might be the factor that differentiates among swimmers who are otherwise similar in physical capacity. In a field of top athletes, the one with superior technique will often have the edge. Thus, integrating coordination-focused evaluation into talent identification could improve our ability to predict which young swimmers have the greatest potential. In the next section, we discuss practical findings and visual evidence that support this theoretical outlook, including how training interventions can enhance coordination.

Discussion of Findings

While our argument is primarily theoretical, emerging empirical findings support the importance of early coordination development. If coordination is crucial for success, we should see measurable improvements in performance metrics when young swimmers work on coordination. Recent pilot studies and coaching interventions provide such evidence. For instance, one training experiment divided adolescent swimmers into two groups for six weeks: a control group doing traditional training and an experimental group receiving augmented feedback on their technique using smart goggles. The feedback focused on encouraging longer, more efficient strokes and better arm timing. The results, summarized in the following charts, align with our hypothesis that focusing on coordination and efficiency yields significant gains.

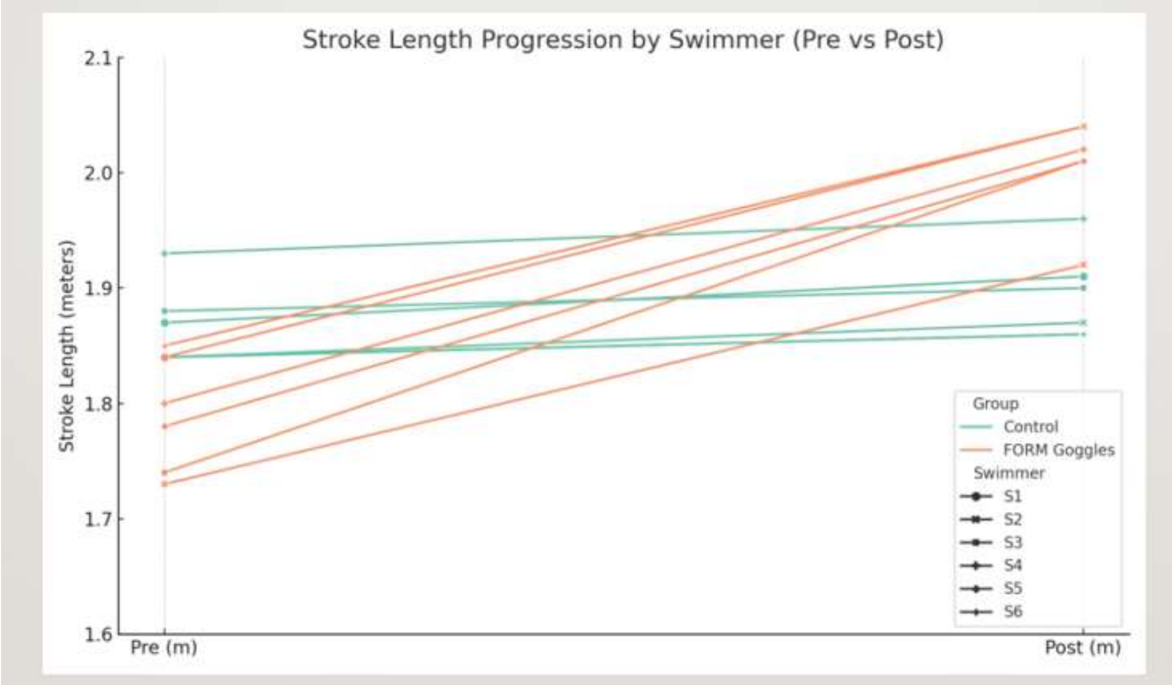

Figure 1: Individual stroke length progression for each swimmer over a 6-week period, comparing a Control group (green lines) with an experimental group using FORM smart goggles for feedback (orange lines). Pre-training values (left) vs post-training (right) show that the feedback group achieved notable increases in stroke length, whereas the control group's stroke length remained nearly flat.

The chart clearly illustrates that every swimmer in the FORM goggles group extended their stroke length (distance traveled per stroke) substantially, indicated by the steep upward trajectories of the orange lines. In contrast, most of the green lines (control swimmers) are nearly horizontal, indicating minimal improvement. Stroke length is a key indicator of efficiency and propulsion effectiveness—longer stroke length at the same or higher speed means the swimmer is moving more water per stroke, often by eliminating inefficiencies. The fact that only the group receiving technique feedback showed large gains suggests that the intervention successfully improved their coordination and propulsion. This supports the idea that young swimmers can rapidly enhance coordination-related metrics with targeted training, and those improvements can translate to better performance potential (since a longer stroke can contribute to faster times when coupled with appropriate rate).

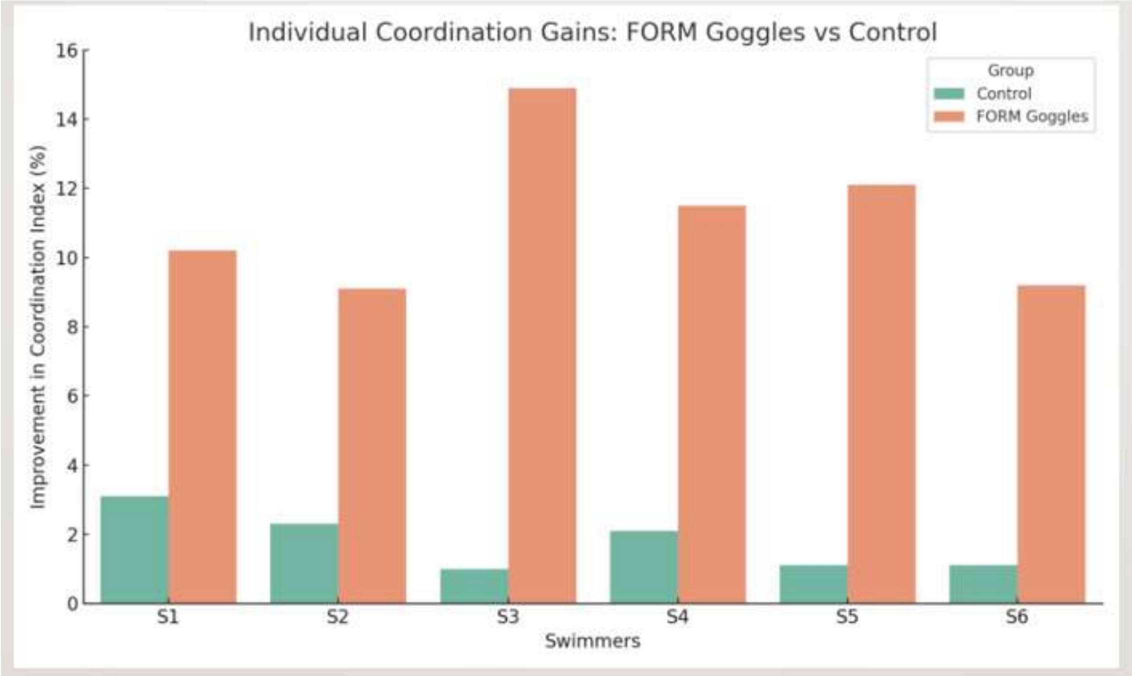

Figure 2: Individual gains in inter-limb coordination index for each swimmer after 6 weeks, with the Control group (green) versus the FORM goggles feedback group (orange). The "Coordination Index" here is measured as an improvement percentage – higher values indicate greater improvement in arm stroke timing symmetry. We see that swimmers S1–S6 in the experimental group achieved markedly higher improvements in coordination (orange bars ranging roughly 9–15% gains) compared to the control swimmers (green bars about 1–3% gains). This coordination index was calculated from video analysis of arm timing, essentially capturing how much each swimmer reduced any lag or imbalance in their arm stroke cycle. The feedback group's consistent, significant improvements demonstrate that focusing on coordination led to quantifiable technical gains. In contrast, the control group, which just did standard training without special feedback, showed only marginal changes. This disparity reinforces the notion that coordination does not automatically improve just by regular training; it improves when specifically targeted. The fact that multiple swimmers in the feedback group

improved their coordination index by over 10% in a short period is encouraging—it suggests that even if a young swimmer starts with suboptimal coordination, they can make rapid progress with the right training emphasis. In the context of our theoretical framework, those swimmers who improved their coordination so significantly would now presumably be able to swim with less glide and more continuous propulsion, positioning them closer to an elite-style stroke. If they carry this forward, one would expect their race performance to improve as well.

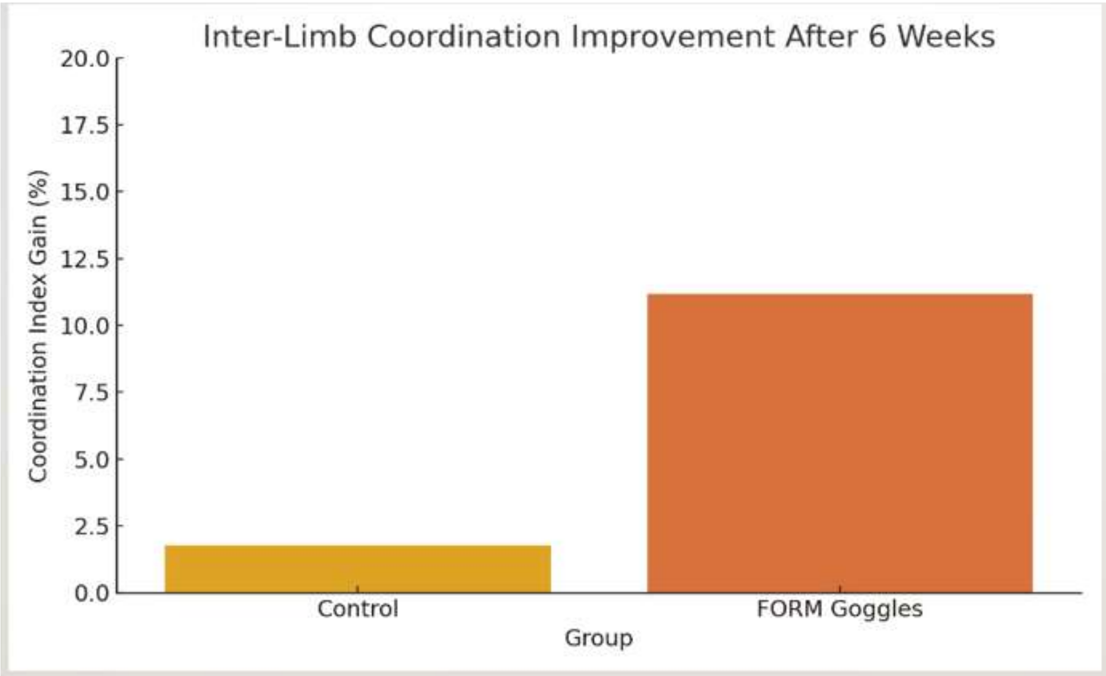

Figure 3: Average improvement in coordination index (%) after 6 weeks for the two groups. The feedback (FORM goggles) group achieved about an 11% average gain in coordination, far surpassing the ~2% gain in the control group. This summary view highlights the dramatic difference in outcome between the two approaches. Statistically, such a gap strongly favors the efficacy of deliberate coordination training. It also underscores a key point: **real-time feedback and focus on stroke coordination significantly accelerates motor learning in young swimmers**. By receiving immediate, objective information (via smart goggles displays or similar) on their stroke, the swimmers could adjust their coordination in ways they likely could not if left to feel alone. After 6 weeks, their strokes were

measurably more symmetrical and overlapping (less catch-up), whereas the control group's strokes stayed roughly the same. For coaches and sport scientists, this serves as practical evidence that investing time in coordination drills and technology can yield improvements in the technical attributes linked to performance. For our argument, it provides a proof of concept that early coordination abilities are malleable and trainable – and that doing so yields better stroke characteristics that are associated with success (continuous propulsion, lower IVV, etc.). If those technical gains are maintained, one would expect the swimmers to swim faster with the same effort, thereby improving their competitive results.

These findings align well with the literature and theory discussed. The improved stroke length (Figure 1) reflects more effective propulsion per stroke, likely due to eliminating minor inefficiencies (for example, reducing an arm's glide phase or a pause in the kick). The improvements in coordination index (Figures 2 and 3) directly reflect better arm timing – swimmers learned to synchronize their arm movements more like seasoned athletes. It is worth noting that the coordination index in this training context was measured as "timing symmetry of arm strokes," which might be slightly different from Chollet's IdC, but the concept is similar: more synchronized, overlapping strokes yield a higher coordination score improvement. The fact that feedback group swimmers achieved upwards of 10% better coordination in timing is significant. In racing terms, a better coordinated stroke can translate to higher speed or less energy cost. For example, if a swimmer previously had a mild catch-up timing and then learned to overlap their strokes by 10% more of the cycle, they have effectively gained continuous propulsion where before there was a gap.

In practical terms, had these swimmers competed after the 6-week program, the expectation is that the feedback group would outperform the control group, all else being equal, because they can now swim more efficiently. While the charts presented are from a small-scale intervention, they provide tangible evidence in support of our theoretical stance: *early improvements in coordination-related metrics directly enhance a swimmer's technical foundation, which is likely to pay off in competitive performance.* The data also suggest that not addressing coordination (as seen in the control group) may lead to stagnation in those skills. One can extrapolate that over longer periods, swimmers who do not develop coordination early might fall behind those who do.

In summary, the discussion of these findings emphasizes that coordination is both critical and trainable. Young swimmers benefiting from coordination-focused training show clear technical advantages over those who do not. These advantages, while demonstrated here in terms of stroke length and timing, are exactly the kind that translate to faster times and better competitive outcomes. This strengthens the argument that coaches should nurture coordination in juniors as a long-term investment in their success.

Conclusions

Coordination abilities in young swimmers emerge as a pivotal factor for future elite success based on the theoretical and empirical evidence reviewed. Elite swimmers distinguish themselves not just by how strong or fit they are, but by **how efficiently they move through the water**, and much of that efficiency comes down to inter-limb coordination and stroke timing. Our exploration finds that swimmers who develop an overlapping, continuous propulsion stroke style early are better positioned to achieve the speeds required at world-class levels. They benefit from lower intracyclic velocity variation (leading to less energy wasted and higher efficiency) [2], and they are able to exploit their strength and conditioning more effectively thanks to superior technique. In contrast, swimmers who remain with a pronounced catch-up stroke or other coordination deficiencies may hit performance ceilings, as they cannot sustain the required velocity without technical adaptation.

The reviewed literature supports the idea that advanced coordination is associated with high performance: Carmigniani et al. showed the necessity of switching to superposition mode at race speeds, and Matsuda et al. demonstrated the link between reduced speed fluctuation and expertise. Our hypothesis extends these findings by suggesting that identifying and cultivating these coordination traits in adolescents can predict and enhance their chances of later success. The illustrative training data further reinforce that coordination is a trainable skill – young swimmers can markedly improve their stroke timing and efficiency in a matter of weeks with proper feedback (Figures 1–3). This implies that talent development programs should include a strong technical focus, ensuring that promising athletes master coordination fundamentals, not just accumulate mileage or muscle.

In practical terms, coaches and scouts could incorporate coordination assessments into their evaluations of young swimmers. Simple tests could include measuring a swimmer's IdC at various speeds (to see if they naturally transition toward overlap at higher effort), analyzing intracyclic velocity stability, or using drills to observe how quickly they can adapt their timing. Those who exhibit advanced coordination patterns or the capacity to improve them rapidly might be flagged as having high performance potential. Likewise, training interventions (like the smart goggle feedback example) can be applied to accelerate coordination development for those who lag in this area. By doing so, we not only improve the athlete's current performance but also set them up with the technical tools needed to excel at senior levels.

It is important to acknowledge that this paper is theoretical; ultimately, longitudinal studies would be invaluable to conclusively prove that early coordination ability predicts adult success. Tracking a cohort of swimmers from youth through to elite competition, with periodic technical measurements, could empirically confirm the proposed link. Nonetheless, the convergence of biomechanical reasoning, cross-sectional studies, and short-term interventions all point to the same conclusion: **teaching young swimmers how to coordinate their movements effectively is an investment in their future podium potential**.

In conclusion, coordination abilities—encompassing stroke timing, rhythm, and the elimination of unnecessary pauses—constitute an important factor (perhaps the hidden X-factor) in determining which young swimmers break through to world championship caliber. By recognizing and fostering these skills early, the swimming community can better nurture its talent, improving the odds that the stars of tomorrow reach their full performance potential. As the sport continues to evolve with new technology and training methods, one constant remains: the harmony between a swimmer's limbs in the water can make the difference between finishing in the pack or touching the wall first. The evidence and arguments presented here reaffirm that mastering that harmony at a young age is key to becoming a champion in the years ahead.

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