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This is a non-final version of an article published in final form in:

Cornett, A., Brammer, C., & Stager, J. (2015). Current Controversy: Analysis of the 2013 FINA World Swimming Championships. *Medicine & Science in Sports & Exercise, 47*(3), 649-654.

and can be found at the Medicine & Science in Sports & Exercise website: http://journals.lww.com/acsm-msse/pages/default.aspx

Medicine & Science IN Sports & Exercise
The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

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Accepted for Publication: 13 June 2014

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000000442

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No external funding was received for this project.

The authors declare no conflict of interest.

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Abstract

Anecdotal reports regarding the 2013 FINA World Swimming Championships held in Barcelona suggested that swim performances were biased, presumably due to a current.

Purpose: The purpose of this study was to analyze the swimmers' performance data in order to determine the merit of these rumors.

Methods: The mean time difference between odd and even 50-meter lengths for each lane in the 1500-meter Freestyle was compared. For each 50-meter event, a percent change in performance from the preliminaries to semifinals and semifinals to finals was calculated for all qualifying swimmers. Observations were grouped according to the swimmers' lane assignments.

Results: For the 1500-meter Freestyle, lane assignment significantly affected the time difference between odd and even 50-meter lengths ($P < 0.001$). The change in performance for the 50-meter events was also affected by lane assignment ($P < 0.001$). When swimmers transitioned from Lanes 1-4 for their first swim (preliminaries or semifinals) to Lanes 5-8 for their second (semifinals or finals), their performance time improved 1.11% (95% CI, 0.82 to 1.41%), which was significantly greater than any other lane change scenario. When swimmers were in Lanes 5-8 for their first swim and Lanes 1-4 for their second, their performance time was slower by 0.59% (95% CI, 0.39 to 0.80%), which was significantly worse than any other lane change combination.

Conclusion: Swimmers were advantaged or disadvantaged depending on the direction and lane in which they swam. The existence of a current is the only cause that we can propose to explain these findings. Since one of FINA's primary stated objectives is to provide fairness in competition, new policies are needed to prevent similar biases from occurring in the future.

Key Words: athletic competition, swimming, analytics, performance, sport

Introduction

Popular author Michael Lewis, in his book entitled "Moneyball," focused national attention on the potential of sophisticated analyses to identify athletic promise and predict the future competitive success of baseball players. The concept did not originate with Lewis; rather, he suggests it originates from the Society of American Baseball Research (SABR) from whose acronym is derived the term "sabermetrics." The basis of sabermetrics is to essentially forgo traditional observation-based physical evaluations and use statistical measures to analyze an athlete's past performance data as a means to predict future success. The modern modus operandi, then, is to make important decisions (e.g., regarding recruiting, hiring, firing, etc.) in professional sport based upon analytical outcomes rather than simple intuition, opinion, or experience.

These same analytic techniques may also be useful as a means of identifying biases in sport. For example, based on analysis of performance data, the expensive 'high tech' suits introduced into swimming in late 2007 were concluded to bias the competition outcome in favor of those with access to them (1). The disproportionate rate of World Record performances provided additional convincing evidence of the magnitude of this bias only after the important competitions were concluded. Nevertheless, suit design limitations were subsequently imposed by the sport's international governing body, the Federation Internationale de Natation (FINA), to constrain competitive suit manufacturers primarily as a means to re-establish competitive fairness (4). The point to be made is, competition biases in sport were, and can be, identified through similar analyses of readily available performance data.

A recent scenario involving competition at the 2013 FINA World Swimming Championships in Barcelona, Spain presents another opportunity to use existent performance data to determine if the competitive outcomes were similarly biased. Anecdotal reports regarding the competition

indicate that a current was present in the pool such that, when swimming toward the finishing end, swimmers were at a competitive disadvantage on one side of the pool and at an advantage on the opposite side. If there was, in fact, a current in the pool during competition, it would have violated FINA regulations which state that water flowing into and out of the pool is "permissible as long as no appreciable current or turbulence is created" (3, p. 392). Flow characteristics of the competition pool cannot be measured, though, because the competitive venue was temporary, built specifically for the World Championships and deconstructed immediately thereafter. However, quantitative analysis of the existing performance data might allow appropriate conclusions to be drawn. Thus, the purpose of this study is to analyze performance data from the 2013 FINA World Swimming Championships to determine whether or not lane assignment affected swim times.

Methods

The performance data for this study came from swim competition results from the 2005, 2007, 2009, 2011, and 2013 FINA World Swimming Championships, and were obtained from the Omega Timing website (7). Further, measurements of speed, stroke rate, and stroke length for 50-meter events were obtained from the 2013 FINA World Swimming Championships website (5). Values were reportedly captured for each ten-meter segment between 15 and 45 meters on each length via "the automated system installed and programmed" by Centro de Alto Rendimiento de Sant Cugat (CAR) and STT Systems. Although the hypotheses only concerned the 2013 competition, results from the 2005, 2007, 2009, and 2011 competitions were also included in an effort to determine whether or not the 2013 results were atypical of FINA World Swimming Championships. Thus, identical analyses were conducted on performance data from

the previous four competitions. The competitions during all five of these international championships were held in 'long course' pools that were 50 meters in length.

In an effort to address the research questions, three separate analyses were conducted. For all statistical analyses, significance was set at an alpha level of 0.05. First, 50-meter splits were analyzed from the 1500-meter Freestyle, an event in which the athletes typically attempt to maintain a fairly even pace throughout most of the race. Consistent with anecdotal reports, it was hypothesized that the time difference between the odd 50-meter lengths (recorded when swimming away from finishing end) and the even 50-meter lengths (recorded when swimming towards the finishing end) from the 1500-meter Freestyle would vary by lane. To eliminate the impact of the start and the tactical aspect of the finish, the 50-meter splits from the first or last 100 meters of the races were not included. Thus, for each preliminary and final 1500-meter performance, an average of 13 odd-length 50-meter splits and 13 even-length 50-meter splits was recorded. The difference between the average odd and average even 50-meter splits was then calculated for each 1500-meter Freestyle performance. A one-way ANOVA was used to determine whether or not lane assignment affected the difference between the odd and even 50-meter splits. It is important to note that in the 1500-meter Freestyle at the FINA World Swimming Championships, all competitors swim in the preliminary round, and then the eight fastest competitors swim again in a final heat. This means that the top eight swimmers have two performances in the data set. Because the focus of this study was to assess the effect of lane assignment on performance measures, and our sample size was already limited, we chose to include all performances in the data set even though this meant that some swimmers would appear twice in the data set. This is a delimitation of the study.

Logically, it would seem that for most races any advantage a swimmer received from swimming in one direction would be counteracted by a disadvantage when swimming in the opposite

direction. However, for the eight events at the FINA World Swimming Championship competitions that are swum in only one direction (Men's and Women's 50-meter Butterfly, Backstroke, Breaststroke, and Freestyle), the presence of a lane bias in the pool could have a major impact on the event results. We hypothesized that the swimmers in Lanes 5-8 were at an advantage in the 50-meter events and the swimmers in Lanes 1-4 were at a disadvantage.

To test whether or not this apparent lane bias affected the performances in the 50-meter events, the percent change in performance time, stroke rate, and stroke length was calculated for all semifinalists (percent change from preliminary heats to semifinal) and finalists (percent change from semifinal to final). For this analysis, as was the case for the 1500-meter Freestyle analysis, the swimmers that qualified for the finals appear in the data set twice. We chose to allow this for the same reasons noted earlier for the 1500-meter Freestyle analysis. Regarding stroke rate and stroke length, three values, representative of 15-25 m, 25-35 m, and 35-45 m distance segments, were averaged and used for analysis. The total sample was (8 50-meter events x 16 semifinalists) + (8 50-meter events x 8 finalists) = 192 observations. Based on the swimmers' lane assignments, each observation was categorized into one of four lane change scenarios (see Table 1). We hypothesized that swimmers with their first swim in Lanes 1-4 and second swim in Lanes 5-8 (LH) would show the greatest improvement in performance time and swimmers with their first swim in Lanes 5-8 and second swim in Lanes 1-4 (HL) would show the least improvement in performance time. For each performance variable, a one-way ANOVA was used to determine whether or not the four scenarios were different with respect to the percent change in performance. In the event of a significant F-ratio, all pairwise comparisons were conducted using Tukey's HSD post hoc test.

**** Table 1 around here ****

Finally, we wanted to test whether or not evidence exists of a lane bias that may have affected the medal winners in the 50-meter events. Before describing the analyses utilized to do so, it is important to note that, in the finals of each event, the fastest swimmer from the semifinal heats was seeded in lane four for the finals, the next fastest swimmer was seeded to the right in lane five, and the remaining swimmers seeded to the left and right in an alternating fashion based on rank. The number of medals won by swimmers competing in Lanes 1-3 and in Lanes 6-8 at the 2013 World Championships were compared to the previous four World Championships. We grouped the lanes in this manner because the swimmers competing in Lanes 4 and 5 are the top two seeds in the race and typically both win medals. As such, the swimmers in Lanes 4 and 5 serve to cancel each other out, which could potentially mask any effect. If the rumored current did exist, the swimmers in Lanes 1-3 would have been at a competitive disadvantage in the 50-meter events while the swimmers in Lanes 6-8 would have been at a competitive advantage. Thus, we hypothesized that more swimmers competing in Lanes 6-8 and fewer swimmers competing in Lanes 1-3 won medals in 2013 as compared to previous FINA World Swimming Championship competitions. A 2x5 (lane group by competition year) contingency table was constructed and analyzed using a Pearson chi square test of independence.

Results

The mean difference between the odd and even 50-meter splits for the 1500-meter Freestyle for each lane is displayed in Figure 1. Lane assignment had a significant effect on the difference between the odd and even 50-meter splits ($P < 0.001$). Tukey's HSD was used to identify which lanes were significantly different with respect to the difference between odd and even 50-meter splits (see Figure 1).

**** Figure 1 around here ****

One-way ANOVA indicated that lane change scenario had a significant effect on the percent change in performance with advancing round ($P < 0.001$). Tukey's HSD showed that the swimmers in LH improved significantly more (1.11%; 95% CI, 0.82 to 1.41%) than when swimmers were in HL (-0.59%; 95% CI, -0.80 to -0.39%), LL (0.19%; 95% CI, -0.20 to 0.58%), and HH (0.43%, 95% CI, 0.20 to 0.67%). In addition, HL showed a decline in performance and this was a significantly worse result than the three other lane change scenarios ($P < 0.05$). HL from the 2013 competition was the only scenario from the past five FINA World Swimming Championships that showed a significant decline in 50-meter performance ($P < 0.05$) with advancing round (see Figure 2).

**** Figure 2 around here ****

The percent change from semifinals to finals for stroke length, stroke frequency, and swim speed were compared across the lane change scenarios. Results showed that stroke length ($P = 0.002$) and speed ($P < 0.001$) changed as a function of lane change scenario, but stroke frequency did not ($P = 0.20$). Tukey's HSD showed that the swimmers in LH increased stroke length significantly more (0.43%; 95% CI, -1.25 to 2.10%) than when swimmers were in HL (-2.97%; 95% CI, -3.85 to -2.09%), LL (-2.23%; 95% CI, -3.80 to -0.66%), and HH (-2.06%; 95% CI, -3.40 to -0.73%). Further, Tukey's HSD showed that the swimmers decreased swim speed significantly more in HL (-1.42%; 95% CI, -2.01 to -0.83%) than when swimmers were in LH (1.08%; 95% CI, 0.61 to 1.56%), LL (0.13%; 95% CI, -0.28 to 0.53%), and HH (0.46%; 95% CI, -0.08 to 1.01%).

The number of medal winners from the 50-meter events for Lanes 1-3 and 6-8 from the past five FINA World Swimming Championships is shown in Table 2. The Pearson chi square test of independence was statistically significant (P = 0.039), which indicates the variables were not independent.

**** Table 2 around here ****

Discussion

Competitive sport operates under the assumption that each competitor's success is determined solely by hard work, commitment, discipline, and talent, and is not influenced by veiled external variables or artificially-contrived biases. However, there are documented circumstances whereby external biases have been shown to unfairly influence sporting outcomes, and other cases in which only rumors of a bias persist. Obviously, a valid mechanism for identifying performance biases is paramount to the maintenance of fairness in competition. The current investigation illustrates that quantitative analysis of existing performance data can be used as a tool to identify the circumstances when and where performances have been subject to some bias. Through careful analysis of the meet results derived from the 2013 FINA World Swimming Championships, our intent was to determine whether or not credible evidence exists in support of the anecdotal reports that a current in the competition venue affected the race outcomes. Our analysis of the race outcomes included multiple inferential procedures performed on the results of the 1500-meter Freestyle and the 50-meter events for all four competitive strokes. And all of our findings regarding these events were consistent with the existence of the rumored current.

The analyses regarding the 1500-meter Freestyle allowed description of the 'direction' of the external bias. As Figure 1 demonstrates, the external bias was not limited to the outer lanes as

the original rumor suggested. Rather, all lanes appeared to be impacted to some extent, and in a very particular manner moving across the pool. The difference between odd and even 50-meter splits was negative for Lanes 1-4 and positive for Lanes 5-8. The magnitude of this difference increased when moving from the center lanes, Lanes 4 and 5, to the outermost lanes, Lanes 1 and 8 (see Figure 1). This provides the initial documentation that swimmers in the 1500-meter Freestyle were faster when swimming away from the finishing end than back towards it on one side of the pool (i.e., Lanes 1-4) and faster when swimming towards the finishing end than away from it on the other side of the pool (i.e., Lanes 5-8).

In addition, our finding concerning the 1500-meter Freestyle illustrated the strength of the external bias. The relationship between lane assignment and the difference between odd and even splits from the 1500-meter Freestyle is statistically significant ($r = 0.87$, $P < 0.001$). Thus, the lane assignment in the 1500-meter Freestyle accounted for 75% of the variance in the difference between the odd and even 50-meter splits. We can put the strength of this relationship into context by calculating the same correlation coefficient for the four FINA World Swimming Championships prior to 2013. In doing so, we find that the championship held in 2007 was the only other competition in which there was a significant relationship between lane assignment and difference between odd and even 50-meter splits for the 1500-meter Freestyle ($r = -0.25$, $P = 0.021$). The relationship was such that the difference between odd and even splits was negative for all lanes, and became increasingly negative moving across the pool from Lane 1 to Lane 8. At the 2007 FINA World Swimming Championships, then, the lane in which the swimmer competed accounted for about 6% of the variance in the difference between odd and even splits. There appears to be relatively little commonality between the two events other that the fact that both the 2007 and 2013 FINA World Swimming Championships were held in 'temporary' pools. Whether or not this common feature played a role in the lane biases is unclear. We were unable

to find any research comparing performances in temporary swimming pools with those in permanent ones.

Analysis of the outcomes of the 50-meter events provided an alternative approach for the estimation of the magnitude of the lane bias. Comparisons were possible between the results of the preliminary heats, semifinal heats, and final heats for the four competitive strokes and both sexes. And like the 1500-meter results, the findings regarding the 50-meter events are pronounced, especially when compared to previous competitions (see Figure 2). However, to interpret these findings, it was necessary to first calculate the typical change in performance with an advance in competitive round. To do so, we computed the change in performance from preliminaries to semifinals and from semifinals to finals for each swimmer competing in the 50-meter events at the past five FINA World Swimming Championships. We determined that, on average, swimmers improve by 0.26% (95% CI, 0.20 to 0.32%; N = 955). Because of this, we expected the swimmers to have improved at the 2013 competition when both swims were on the same side of the pool (the LL and HH lane change scenarios). And that is what happened: when swimmers were in LL, they improved by 0.19%, and when swimmers were in HH, they improved by 0.43%. But importantly, while these improvements were significantly greater than zero, they were not statistically different from the mean improvement observed over the course of the five FINA World Swimming Championships from 2005-2013 (i.e., 0.26% improvement).

On the other hand, when a swimmer's lane assignment switched from one side of the pool to the other with an advance in round (the LH and HL lane change scenarios), the results differed. When swimmers were in LH, their performances improved significantly more (1.11% improvement) than what we determined as being typical (0.26% improvement; $P < 0.05$). This improvement was more than double that of any lane change scenario from any FINA World Swimming Championship competition held from 2005-2013 (see Figure 2). One explanation for

this finding is simply that swimmers improved to such an extent because they swam against a current during their first swim and swam with the current during their second swim. We also confirmed the other extreme, that being when swimmers were in HL. Our comparison showed that these swimmers were, on average, 0.59% slower than they were during the previous competitive round. This was the only lane change scenario documented to swim slower with advancing rounds at the FINA World Swimming Championships between 2005 and 2013 (see Figure 2). All other groups analyzed showed a significant improvement or no change in performance. Once again, this result is consistent with the explanation that a current existed in the 2013 competition pool such that swimmers' performances were worse because they swam with a current during their first swim and swam against a current during their second swim.

If the presumed pool current caused the performance bias, then logically one or more of the determinants of swim speed must be affected as well. Though the mechanics of human propulsion in the water are only partially understood, it is accepted that swim speed can be viewed as the product of stroke rate and distance per stroke (2). It stands to reason, then, that differences in stroke length and/or stroke rate would be apparent. Consistent with the analyses of performance times, swimmers in LH had between 2.5 and 3.4% greater stroke length than the three other lane change scenarios. Further, swimmers in HL were between 1.5 and 2.5% slower than the three other lane change scenarios. While in parallel with our prior analyses, we readily recognize that this analysis of stroke length, stroke rate, and swim speed can only be considered circumstantial evidence as little is known about the data collection procedures. We cannot, therefore, defend the accuracy, precision, and validity of these data. Nevertheless, because the comparisons were statistically significant, and theoretically consistent with our other analyses, they lend further confirmation of the rumored pool current.

The 2013 FINA World Swimming Championships is not the first instance in which an external bias was shown to impact the results of a major international competition (1,6). The most pertinent example comes from the sport of track and field, and is especially relevant because it involved the recognition of a lane bias that was subsequently corrected through an analysis of available performance data (6). Briefly, Julin and Dapena (6) explained that at the 1996 Olympic Games start times differed by lane assignment, despite a loudspeaker that transmitted the sound of the starter's gun being placed next to each starting block. Further, the difference in start time corresponded with the distance each lane was from the starting gun. Because sound travels through the air at a speed of approximately 350 ms^{-1}, it takes an additional 0.03 s for the sound from the starter's gun to reach an athlete for every 10 m of distance that an athlete is from the starter's gun. It appeared the athletes were still responding to the sound of the gun transmitted through the air, not the sound transmitted through the loudspeaker system. Thus, the athletes who were positioned farther from the starting gun were at a competitive disadvantage.

This example from the sport of track and field demonstrates an important and relevant point. Analysis of performance data can and should be used to identify biases influencing the outcomes of athletic competitions. In response to the unfair competitive venue, the International Association of Athletics Federations, the world governing body for track and field, mandated new regulations that required different start technology to eliminate the bias. The analysis of performance data from the 2013 FINA World Swimming Championships revealed a similar lane bias, but it remains to be seen whether or not changes will be mandated to eliminate this bias at future swim competitions.

Conclusions and Recommendations

The 2013 FINA World Swimming Championships was held in a temporary swim pool, built specifically for the event and taken apart immediately afterwards. As such, it is impossible to conduct any direct testing of the physical properties of the competition facility. Instead, analyses of the performance data allowed confirmation of the rumors that a current existed in the pool during competition. And while it cannot be definitively concluded that there was a current in the pool, *the results of all of the analyses* suggest that this was, indeed, the case. Swimmers were at a competitive advantage when swimming towards the finishing end on one side of the pool (Lanes 5-8) and at a competitive disadvantage when swimming in the same direction on the other side of the pool (Lanes 1-4). This advantage was evident in the final meet results of the 50-meter events where a disproportionate number of swimmers won medals when swimming in Lanes 6-8. But the purpose of this paper was not necessarily to dwell on medals that 'might have been.' Rather, the focus is centered upon future competitions. It is hoped that the evidence provided herein will force the swimming community to consider how similar lane biases can be prevented at subsequent competitions. It is recommended, as a result of these findings, that FINA recruit the assistance of engineers and other pool design experts to assess, advise and limit the potential for currents to influence race outcomes. From continued, informed dialog among these experts, new regulations can be put forth that fulfill one of FINA's primary stated objectives: *to provide fairness in competition*.

Acknowledgments

The authors would like to thank Magdalena Kuras and Jason Marsteller for making us aware of the rumoured bias, and Neal Cassady for driving the bus.

No external funding was received for this project.

Conflicts of Interest

The authors declare no conflict of interest.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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Figure Captions

Figure 1. The difference between the odd and even 50-meter splits from the 1500-meter Freestyle at the 2013 FINA World Swimming Championships as a function of lane. Error bars represent the 95% confidence interval around the mean. Significant differences between pairs of lanes are indicated by the numbers above each lane ($P < 0.05$).

Figure 2. The percent change in performance from preliminaries to semifinals or from semifinals to finals for the four lane change scenarios, which represent the lane assignments for the pair of swims, at the 2005, 2007, 2009, 2011, and 2013 FINA World Swimming Championships. Error bars represent the 95% confidence interval around the mean. Swimmers that competed in lanes 1-4 or 5-8 for both swims were assigned to LL and HH, respectively; swimmers that competed in lanes 1-4 for their first swim and lanes 5-8 for their second swim were assigned to LH; and swimmers that competed in lanes 5-8 for their first swim and lanes 1-4 for their second swim were assigned to HL. There was one occasion at the past five World Championships where a scenario showed a significant decline in performance ($P < 0.05$) and that was HL in 2013. All other groups showed a significant improvement or no change in performance.

Figure 1

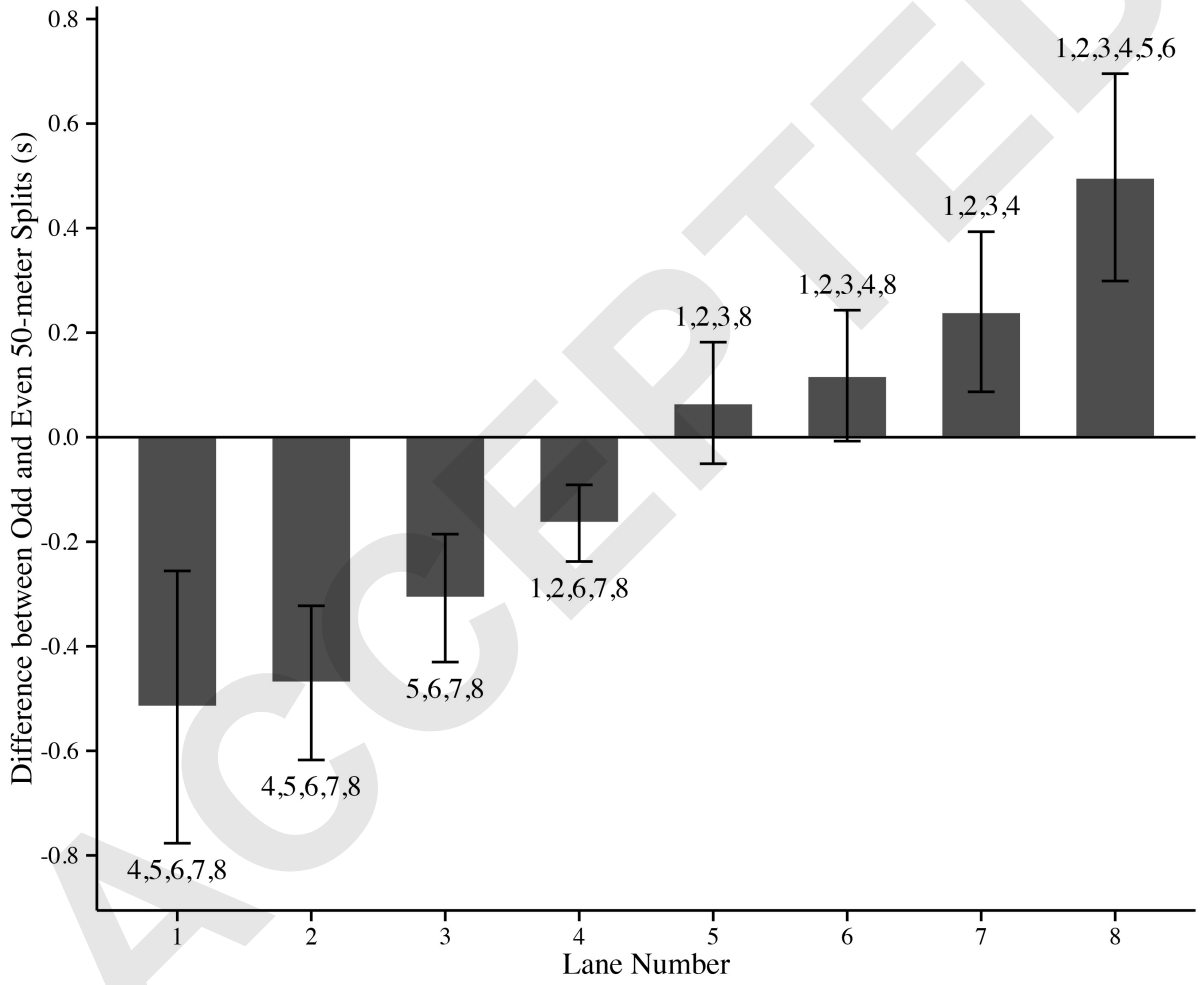

Figure 2

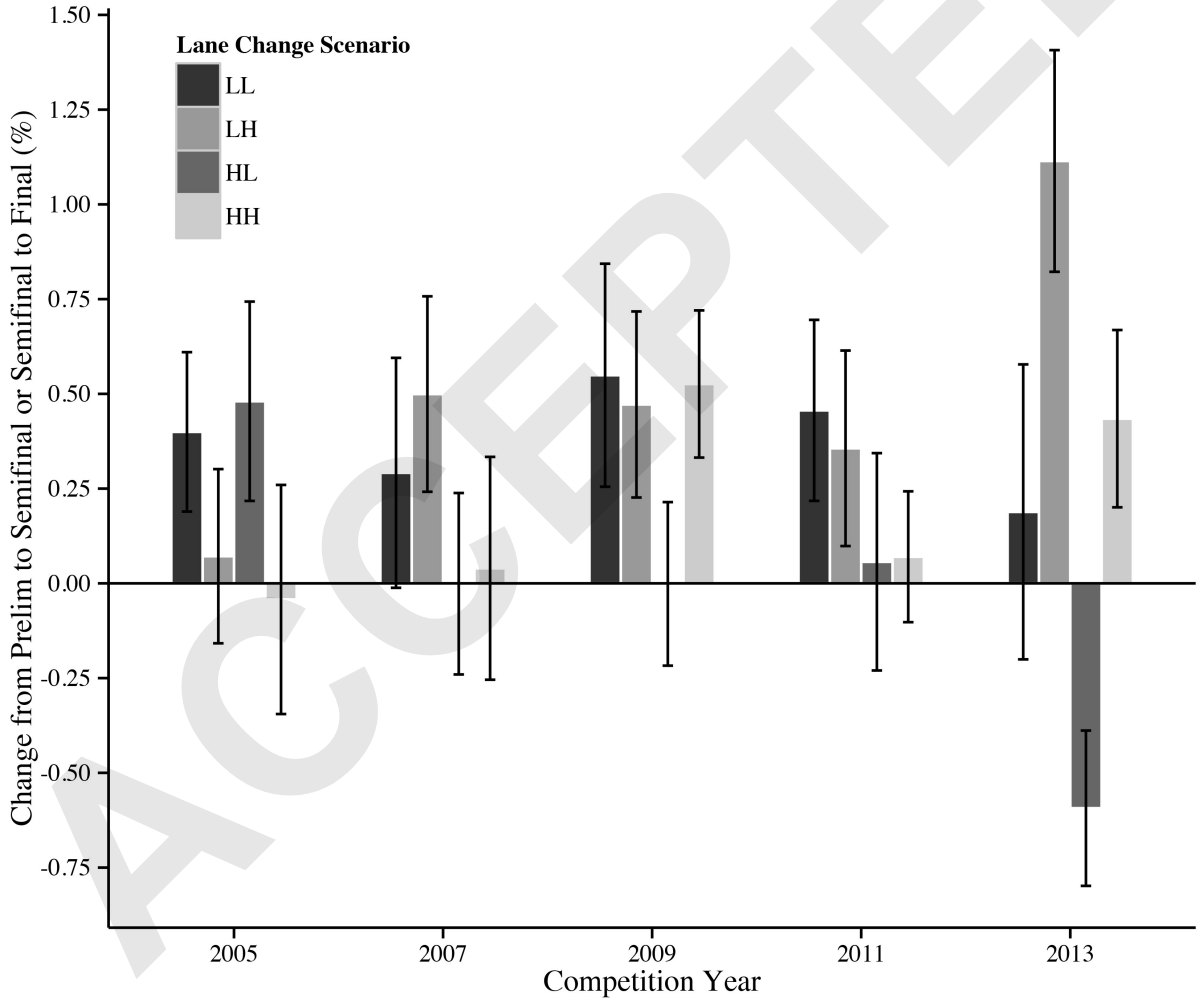

Table 1. Lane change scenarios for swimmers that qualified for semifinals and finals in the Men's and Women's 50-meter events at the 2013 FINA World Swimming Championships.

Lane Change Scenario	Lane in First swim	Lane in Second swim
LL	1-4	1-4
LH	1-4	5-8
HL	5-8	1-4
HH	5-8	5-8

Note: For each swimmer, their first swim was either a preliminary swim or a semifinal swim and their second swim was either the semifinal or final swim, respectively. L = low numbered lanes, H = high numbered lanes.

Table 2. The number of medals won by swimmers in lanes 1-3 and 6-8 at the past five FINA World Swimming Championships.

Lanes	2005	2007	2009	2011	2013
1-3	9	5	9	6	1
6-8	3	5	7	5	11

Note: Pearson chi square test of independence was significant, $\chi^2(4) = 10.11$, $P = 0.039$.