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Lane bias in elite-level swimming competition

Christopher Brammer[a], Andrew Cornett[b] and Joel Stager[a]

[a]Indiana University, Counsilman Center for the Science of Swimming, Bloomington, IN, USA; [b]Eastern Michigan University, School of Health Promotion and Human Performance, Ypsilanti, MI, USA

ABSTRACT

Performance outcomes at the 2013 World Swimming Championship were previously shown to be biased depending on the swimmer's lane assignment. The purpose of this study was to determine if this kind of bias was unique, and if not, if the bias was related to the temporary or permanent nature of the pool. The effect of lane on the average odd-length split minus the preceding even-length split in the 800- and 1500-m freestyle events, and on the relative change from qualifying to preliminary performance in the 50-m events, was determined for 16 other elite-level competitions. Depending on the swimmers' direction, split times were on average 0.16 s slower or faster in at least one lane at each of the 16 competitions, and in 49% of all lanes analysed. In 5 competitions, swimmers were shown to be faster in a *majority of lanes* in one direction as compared to the other. Analysis of the 50-m events at these 5 competitions indicate that preliminary performances were between 0.5 and 0.9% slower or faster than qualifying times, which is consistent with the direction effect observed in the distance freestyle events. Further, lane biases occur more often in temporary pools (70% of lanes) than in permanent pools (35% of lanes), with water currents as the most plausible cause. The prevalence of lane bias at elite-level swimming competition highlights the need for the implementation of policies and procedures to prevent such bias from occurring again in the future.

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KEYWORDS
Analytics; performance; sport

Introduction

An analysis of performance data from the 2013 World Swimming Championship provided evidence of a lane bias occurring during the competition (Cornett, Brammer, & Stager, 2015). The times for the 50-m splits obtained from the 1500-m freestyle event were dependent on the lane to which the swimmer was assigned and the direction the swimmer was moving. The nature of the bias was such that on one side of the pool, the swimmers were consistently faster when swimming towards the finishing end as compared to swimming away from it, and on the other side of the pool were consistently slower when swimming towards the finishing end as compared to away from it. This was especially problematic for the 50-m events during which swimmers complete a single length of the pool, and therefore swim in one direction for the entire race. Consistent with the effects observed for the 1500-m event, on one side of the pool, 50-m event performances were facilitated while on the other side, they were inhibited. As a result, swimmers were either advantaged or disadvantaged in all 50-m events dependent upon lane assignment, with the greatest effect occurring in the outermost lanes. Whether or not the lane bias at the 2013 championships was an isolated occurrence remains unknown because elite-level performances at comparable swim competitions have not been similarly analysed. The possibility exists, however, that lane biases are not rare in competitive swimming and that other competitions may have been similarly affected.

Cornett et al. (2015) concluded that the lane bias at the 2013 World Swimming Championship was consistent with a circular pool current that favoured athletes in some lanes over others. However, while the analytic results support the existence of a pool current, direct scientific measurement of the physical properties of the pool was not possible as the 2013 championship was held in a temporary tank – immediately deconstructed following the competition's completion. Whether or not the inherent design of this temporary pool was flawed or its installation was causal to the bias is now impossible to determine. The possibility exists that permanent facilities are just as prone to lane biases as temporary venues. Either way, additional analyses of elite-level competitions appear warranted.

Thus, this study's primary purpose was to analyse swim performance data as a means to determine if additional evidence of lane biases at past elite-level competitions exists. The working hypothesis was that there is no reason to suppose that the observed lane bias was an isolated case and that similar biases would be confirmed during other competitions. Secondarily, in the event that lane biases were prevalent, the issue would be addressed as to whether or not the pool type (i.e., temporary vs permanent) is associated with a greater or lesser incidence of lane bias. If so, these findings would force additional dialogue in order to formulate appropriate regulatory policies preventing lane biases from influencing future competitive outcomes.

CONTACT Christopher Brammer brammerc@indiana.edu 1025 E 7th St., Bloomington, IN 47405, USA
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Methods

Performance results from the 800- to 1500-m freestyle events (distance freestyle), and all 50-m events for all strokes (freestyle, backstroke, butterfly and breaststroke), where applicable, were derived from the official results of international and US national swim competitions from 2000 to 2013 ($N = 17$ competitions), and were downloaded from the Omega Timing (2015) (www.omegatiming.com) and USA Swimming (2015) (www.usaswimming.org). All Olympic Games and World Championship competitions since the year 2000 were included in the data set, with the only exception being the 2001 World Championships, whose results were unavailable. In addition, the US National and Olympic trial competitions from the third and fourth year of each Olympic quadrennial since 2000 were included. These competitions were selected in an attempt to balance the number of temporary ($N = 7$) and permanent ($N = 10$) pools and the competition level among the championship events was included within the data set. All competitions met Federation Internationale de Natation Amateur (FINA) accreditation requirements for 50-m competitions, with the finishing end being the same as the starting end for all events except the 50-m events. Thus, for the sake of clarity, description of the swimmers' motion is made relative to the finishing end (i.e., swimming towards or away from the finishing end). Approval for this study was obtained by the local Institutional Ethics Committee.

In total, performances from 1160-distance freestyle swimmers and 3638 50-m event swimmers were analysed. For each performance, the name of the competition, competition date, swimmer name, sex, event, lane, each 50-m split and total performance time were recorded. There were 632-distance freestyle swimmers and 772 50-m event swimmers who appeared more than once within a given competition. In addition, 164-distance freestyle swimmers and 101 50-m event swimmers swam in more than one competition. However, because the focus of this study was to assess the effect of lane assignment on measures of performance, and our sample size for a given lane within a given competition was limited, we chose to ignore individual participant variation both between and within competitions. This approach is likely conservative given that some of the distance freestyle split variability might be accounted for by considering intra-individual variation. Sample size for each lane ranged from 6 to 12, 12 to 30 and 12 to 36 for the Olympic Games, World Championships and US National and Olympic Trials competitions, respectively.

In an effort to address the prevalence of lane bias, we first conducted an analysis of the 800- and 1500-m freestyle (distance freestyle) events to determine if 50-m splits were faster in one direction versus the other. If significant direction effects (i.e., swimmers were faster in one direction vs the other) were evident during the distance freestyle events, two additional analyses were planned. The first additional analysis was designed to determine whether or not performance outcomes in the 50-m events were affected in a manner consistent with the direction effect observed in the distance freestyle events. The second additional analysis addressed whether or not the occurrence of affected lanes was different between temporary and permanent venues. These analyses are detailed in the following paragraphs. An alpha level of 0.05 was used to determine significance for all statistical tests.

The 50-m splits from the first and last 100 m of the 800- and 1500-m races were not included so as to eliminate the impact of the start and the finish. In addition, for each performance, any systematic trend in distance freestyle splits (such as from strategy or fatigue) was accounted for by fitting a lowess curve with the width of the sliding window equal to 4 50-m splits ($\alpha = 0.15$ for 1500 m and $\alpha = 0.33$ for 800 m; Cleveland, 1979). Essentially, the lowess procedure calculates weighted least squares regression equation within a window containing the nearest 4 split times at each value along the abscissa. Since the regressions are local, the estimated slopes change to follow the shape of the data, thus accounting for the systematic change in performance. Next, the residuals from the lowess curve fit were calculated for each distance freestyle performance.

To answer the question of whether or not swimmers in a particular lane or competition swam faster in one direction versus the other, the residual from each odd-length 50-m split was paired with the residual from the previous even length 50-m split. The mean difference between each odd-length and even-length residual pair for each individual distance freestyle performance was calculated, a value we refer to as the odd minus even-split difference (OMESD). OMESD is a value that can be thought of as the time difference between consecutive 50-m splits, excluding any systematic changes in swim speed. To determine if swimmers swam slower when moving towards the finishing end in a given lane (i.e. slower on even-length 50-m splits), a binomial analysis compared the percentage of swimmers whose average OMESD's were below zero to the expected value of 50%. Alternately, to determine if swimmers swam faster when moving towards the finishing end (i.e., faster on even-length 50-m splits), the percentage of swimmers whose average OMESD's were above zero was compared to the expected value of 50%. Because this study was concerned with the direction effect in a given lane and not the effects of sex or event within or between competitions, these statistics were collated across event and sex for each competition. That is, the percentage of swimmers whose average OMESD's were above or below zero represented the proportion of *all* swimmers who swam in a particular lane at a given competition. Coupled with the binomial analysis, the magnitude of differences between odd and even-length splits for each lane at each competition was quantified as Cohen's *d* effect sizes. Cohen's *d* was calculated as the mean OMESD of all swimmers within a given lane divided by the between-swimmer standard deviation. Cohen's *d* effect sizes were evaluated as trivial (0–0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99) and very large (2.00–3.99) according to Hopkins, Marshall, Batterham, and Hanin (2009).

Next, if distance freestyle splits were shown to be affected by the swimmer's direction in the *majority of lanes* at a competition, then the 50-m events at that competition were analysed to determine if performance outcomes were affected in a manner consistent with the direction effect seen in the distance freestyle events. For these competitions, the percent change between the log of qualifying time and the log of preliminary performance was calculated for each 50-m event competitor such that positive values reflected an improvement in performance. In an effort to remove outliers, percent change values that were more than 1.5 × the fourth spread above or below the upper and lower fourth, respectively, were eliminated (Hoaglin, Mosteller, & Tukey, 1983). Then, each lane was categorised into 1 of 3 Lane Groups based on the distance freestyle analyses: 50-m splits were slower towards the finishing end than away from it (a moderate or greater negative direction effect), 50-m splits were not dependent on the direction the swimmer was moving (a trivial or small direction effect) or 50-m splits were faster towards the finishing end than away from it (a moderate or greater positive direction effect). For each competition, a one-way analysis of variance (ANOVA) was used to compare the percent change in 50-m performance between each Lane Group. Pairwise comparisons were made using Tukey's *post hoc* test for all significant *F*-ratios.

Finally, in the event that significant direction effects were detected in the distance freestyle events, chi-square tests of independence were performed to test whether or not the existence of a direction effect was related to pool type (i.e., temporary or permanent pool) and whether or not the nature of the direction effect (i.e., faster or slower towards the finishing end) was associated with pool type.

Results

Sixteen of the 17 competitions analysed had at least 1 lane in which the average OMESD was either above or below zero for significantly more than half the distance freestyle swimmers in that lane (Table I). Swimmers' 50-m splits were 0.16 s (95% CI, 0.13–0.18 s) *slower* when swimming towards the finishing end than away from it (a negative direction effect) in 53 of the analysed lanes across the 16 competitions. The average standardised mean effect (Cohen's *d*) of direction for these lanes was moderate: −1.00 (−1.15 to −0.84). On the other hand, swimmers were 0.16 s (0.11–0.21 s) *faster* swimming towards the finishing end than away from it (a positive direction effect) in 17 lanes across 6 competitions. The average standardised mean effect of direction for these lanes was moderate to large: 1.04 (0.71–1.37). There were 74 lanes in which there was no direction effect, with a mean split difference of 0 s (−0.01 to 0.01 s) and trivial mean effect size of 0.03 (−0.05–0.11). Table II details the magnitudes of the effects of direction on distance freestyle splits. Table II displays the 95% confidence limits for mean OMESD for each lane analysed.

Based on the initial distance freestyle analyses, 5 competitions were identified during which the 50-m splits from the majority of lanes were shown to be dependent on the swim direction. These competitions included the 2000 Olympic Games, the 2007, 2011 and 2013 World Championships, and the 2012 US Olympic Trials. At each of these 5 competitions except the 2007 World Championships, the mean percent change from qualifying time to preliminary 50-m event performance was significantly better for swimmers in the Lane Group in which there was a trivial or small direction effect compared to the Lane Group in which there was a moderate or greater negative direction effect (−0.24 vs −1.12, −0.28 vs −0.88, −0.44 vs −1.33 and −0.14 vs −0.88%, respectively; 95% confidence interval (CI) shown in Table III). In addition, at both the 2013 World Championships and 2012 US Olympic Trials, preliminary 50-m event performances were significantly better relative to qualifying times for swimmers in the Lane Group in which there was a moderate or greater positive direction effect than they were for the Lane Group in which there was a moderate or greater negative direction effect (−0.79 vs −1.33 and 0.39 vs −0.88%, respectively). All lanes at the 2007 World Championship had a moderate or greater negative direction effect, and thus no Lane Group comparisons could be made. Table III displays the 95% CI about the mean percent change from qualifying to preliminary performances in 50-m events.

Chi-square tests of independence revealed that pool type (i.e., temporary or permanent) was associated with a direction effect (χ^2 (1) = 17.62, P < 0.001) and whether or not distance

Table I. Standardised mean effect of swimmers' direction on distance freestyle 50-m splits (800- and 1500-m freestyle). Values are Cohen's *d* effect sizes and were calculated as the mean of swimmers' odd minus even-length split differences divided by the standard deviation of those differences. An asterisk (*) indicates either significantly more than half of the swimmers in a lane were faster (positive values) or slower (negative values) when swimming towards the finishing end than away from it. Pool type refers to either permanent (P) or temporary (T).

			Lane									
	Pool type	Year	0	1	2	3	4	5	6	7	8	9
Olympic Games	P	2000	NA	−1.10*	−1.03*	−1.24*	−1.08*	−0.89*	0.05	0.52	0.39	NA
	P	2004	NA	−0.07	−0.66	−0.27	0.05	−0.22	−0.41	−0.15	−0.02	NA
	P	2008	NA	0.42	−0.17	−0.45*	−0.46	0.29	−0.85*	−0.60	0.18	NA
	P	2012	NA	−1.23*	−1.34*	−0.72	0.14	0.19	−0.16	−1.39*	−0.58	NA
World Championships	T	2003	NA	−0.21	0.11*	0.71*	0.70*	0.41	−0.06	−0.22	−0.45*	NA
	P	2005	NA	0.58	−0.22*	−0.48*	−0.29*	−0.20	−0.07	0.19	0.25	NA
	T	2007	NA	−0.86*	−1.40*	−2.37*	−1.63*	−0.69*	−1.21*	−1.31*	−1.65*	NA
	P	2009	−0.55	−0.35	−1.16*	−0.57	−0.49*	−0.63*	0.15	−0.53*	−0.33	−1.35*
	T	2011	NA	0.10	−0.89*	−0.45*	−0.68*	−1.04*	−0.95*	−0.48	−0.12	NA
	T	2013	−1.66*	−1.75*	−2.14*	−2.44*	−1.26*	0.56	0.72*	1.48*	3.05*	2.21*
US National and Olympic Trials	P	2000	NA	−0.52	0.11	0.12	−0.05	0.06	−0.23*	0.30	0.51	NA
	P	2003	NA	−0.21	−0.40*	−0.67*	−0.34	−0.51*	−0.17	−0.01	−0.62*	NA
	T	2004	NA	0.17	0.86	1.49*	0.24	0.04	0.74*	−0.15	−1.39*	NA
	P	2007	NA	−0.67*	−0.30*	−0.21	−0.08	−0.26*	−0.52	−0.25	−0.15	NA
	T	2008	NA	0.21	−0.39*	0.11	−0.35*	0.27	0.55*	0.88*	0.20	NA
	P	2011	0.84	−0.18	−0.23	−0.07	0.05	−0.51*	0.35	−0.20	0.64*	−0.60*
	T	2012	1.23*	0.70*	0.90*	0.82*	0.75*	−0.02	−0.16	−1.28*	−1.57*	−2.17*

Table II. Total 95% confidence interval for the mean odd minus even 50-m split difference (in seconds) during the distance freestyle events (800- and 1500-m freestyles). Data were collapsed across event and sex such that the interval was representative of *all* swimmers in a given lane at a given competition. Negative values indicate swimmers were slower when swimming towards the finishing end than away from it. Mean sample size for each lane was 10, 22 and 21 for Olympic Games, World Championships and US National and Olympic Trials, respectively.

		Lane									
	Year	0	1	2	3	4	5	6	7	8	9
Olympic Games	2000	NA	−0.26 to −0.17	−0.24 to −0.15	−0.26 to −0.16	−0.12 to −0.05	−0.16 to −0.08	−0.01 to 0.09	0.08–0.19	−0.01 to 0.09	NA
	2004	NA	−0.09 to 0.03	−0.21 to −0.09	−0.05 to 0.04	−0.02 to 0.07	−0.04 to 0.05	−0.08 to 0.01	−0.04 to 0.07	−0.05 to 0.05	NA
	2008	NA	−0.02 to 0.10	−0.04 to 0.04	−0.12 to −0.05	−0.08 to 0.00	0.02–0.10	−0.19 to −0.08	−0.09 to 0.00	−0.03 to 0.06	NA
	2012	NA	−0.24 to −0.14	−0.19 to −0.11	−0.13 to −0.04	−0.01 to 0.09	−0.02 to 0.07	−0.12 to 0.00	−0.20 to −0.12	−0.15 to −0.05	NA
World Championships	2003	NA	−0.08 to −0.01	−0.02 to 0.05	0.03–0.09	0.08–0.15	0.02–0.10	−0.03 to 0.04	−0.12 to −0.03	−0.09 to −0.02	NA
	2005	NA	0.07–0.14	−0.07 to 0.01	−0.12 to −0.04	−0.12 to −0.05	−0.09 to −0.02	−0.06 to 0.01	−0.01 to 0.09	−0.02 to 0.10	NA
	2007	NA	−0.20 to −0.12	−0.27 to −0.20	−0.36 to −0.29	−0.28 to −0.21	−0.26 to −0.18	−0.23 to −0.15	−0.26 to −0.19	−0.31 to −0.24	NA
	2009	−0.12 to −0.01	−0.09 to −0.02	−0.26 to −0.18	−0.13 to −0.06	−0.09 to −0.02	−0.12 to −0.05	−0.04 to 0.03	−0.11 to −0.04	−0.10 to −0.02	−0.30 to −0.19
	2011	NA	−0.02 to 0.07	−0.21 to −0.14	−0.13 to −0.06	−0.13 to −0.06	−0.21 to −0.13	−0.14 to −0.08	−0.14 to −0.06	−0.02 to 0.06	NA
	2013	−0.34 to −0.21	−0.40 to −0.31	−0.45 to −0.38	−0.35 to −0.29	−0.21 to −0.14	0.05–0.12	0.09–0.17	0.23–0.32	0.37 to 0.44	0.34 to 0.43
US National and Olympic Trials	2000	NA	−0.08 to 0.00	0.00–0.08	−0.01 to 0.07	−0.04 to 0.03	−0.02 to 0.05	−0.10 to −0.02	0.00–0.07	0.04 to 0.12	NA
	2003	NA	−0.06 to 0.01	−0.10 to −0.04	−0.14 to −0.07	−0.09 to −0.03	−0.09 to −0.03	−0.04 to 0.01	−0.06 to 0.00	−0.13 to −0.06	NA
	2004	NA	−0.01 to 0.11	0.12–0.22	0.12–0.22	−0.03 to 0.06	−0.05 to 0.05	0.09–0.19	−0.11 to 0.01	−0.33 to −0.20	NA
	2007	NA	−0.16 to −0.09	−0.06 to 0.00	−0.04 to 0.02	−0.07 to 0.00	−0.06 to 0.00	−0.10 to −0.04	−0.05 to 0.01	−0.02 to 0.05	NA
	2008	NA	0.03–0.13	−0.12 to −0.03	−0.04 to 0.04	−0.06 to 0.00	0.01–0.10	0.00–0.08	0.14–0.22	−0.02 to 0.07	NA
	2011	0.10–0.19	−0.03 to 0.04	−0.04 to 0.04	−0.05 to 0.03	−0.04 to 0.04	−0.11 to −0.03	0.02–0.10	−0.06 to 0.01	0.09 to 0.17	−0.16 to −0.06
	2012	0.19–0.27	0.06–0.15	0.12–0.20	0.08–0.15	0.06–0.13	−0.04 to 0.04	−0.10 to −0.02	−0.20 to −0.12	−0.24 to −0.17	−0.37 to −0.29

Table III. Percent change from qualifying time to preliminary performance for 50-m events (data represent 95% confidence interval). Negative values indicate preliminary performances were slower than qualifying times. A given lane's performances were categorised into Lane Groups based on the effect of direction on distance freestyle splits (see Table I), with inclusion criteria defined as follows: the lane had a moderate or greater negative direction effect, the lane had a small or trivial direction effect (no effect), or the lane had a moderate or greater positive direction effect during the distance freestyle events.

		Lane group					
	Year	Negative effect	*n*	No effect	n	Positive effect	*n*
Olympic Games	2000	−1.48 to −0.77	86	−0.76 to 0.27[1]	50		
World Championships	2007	−1.04 to −0.78	833				
World Championships	2011	−1.08 to −0.67	272	−0.55 to 0.00[1]	160		
US Olympic Trials	2012	−1.60 to −1.06	95	−0.73 to −0.15[1]	64	−0.99 to −0.60[1]	161
World Championships	2013	−1.08 to −0.68	258	−0.45 to 0.18[1]	57	0.18 to 0.60[1]	204

[1] Significantly greater than the negative effect Lane Group ($P < 0.05$).

freestyle swimmers were faster when swimming towards the finishing end than away from it (χ^2 (1) = 21.82, $P < 0.001$).

Discussion

Athletes, coaches and spectators expect competitive sport outcomes to be determined by factors such as training, technique and race strategy, not by veiled external variables. For this reason, concluding that the outcomes of the 2013 World Swimming Championship were likely impacted by something as seemingly trivial as lane assignment was disconcerting (Cornett et al., 2015). Analyses determined that swimmers at that meet were assisted when swimming in one direction and resisted when swimming in the opposite direction, and the magnitude and direction of the effect were dependent upon lane assignment. To add to this conundrum, the collective results of the present study provide strong evidence that the lane bias observed at the 2013 World Swimming Championship was neither an isolated case nor unique.

Our analyses revealed that 50-m splits from the distance events were indeed affected by direction in at least 1 lane at 16 of the 17 competitions and in 70 (49%) of the 144 lanes analysed (Table I). Within the 70 lanes affected, 50-m splits were slower towards the finishing end than away from it in 53 (76%) of the lanes and faster towards the finishing end than away from it in the 17 (24%) remaining lanes. The specific manner in which lanes were affected varied between competitions, with some competitions in which lanes on one side of the pool had a negative direction effect (e.g., the 2000 Olympic Games and 2011 World Championships), and others in which both a negative and positive direction effect occurred on opposite sides of the pool (e.g., the 2012 US Olympic Trials and 2013 World Championships). In the unique case of the 2007 World Championships, *all* lanes had a negative direction effect. The prevalence of a direction effect in elite-level swimming competition is an obvious cause for concern, but because the performance outcomes of the distance freestyle events were not directly analysed, the presence of a positive or negative direction effect for a lane does not necessarily mean the swimmers in that lane had an unfair competitive advantage (or disadvantage). However, the distance freestyle analyses did serve to illuminate the venues in which a direct analysis of 50-m event outcomes could be used to additionally confirm the existence of specific lane biases.

Because the 50-m events consist of swimming a single length of the pool, we reasoned that 50-m performances in any particular lane would be affected in a manner consistent with the direction effect that was identified using the data from the distance freestyle analysis. If, in fact, the results of the 50-m analysis agree with those derived from the distance freestyle analyses, then together they would act to strengthen the evidence pertaining to the existence of biased outcomes. We focused upon the 5 competitions in which distance freestyle split times were dependent on the direction of travel in a majority of lanes because in these competitions there was clear evidence of a systematic trend. At the 2000 Olympic Games, the 2011 and 2013 World Championships, and the 2012 US Olympic Trials, in the lanes where there was a moderate or greater negative direction effect in the distance freestyle events, the 50-m event preliminary performances were significantly worse relative to qualifying times as compared to the lanes in which there was either a positive direction effect or no direction effect (Table III). Although 50-m performances in the lanes in which there was a significant positive direction effect were not shown to be better than those in the lanes with no direction effect, the overall findings still support the conclusion that some swimmers were unfairly (dis)advantaged based on lane assignment in these 4 competitions.

Although the factor(s) responsible for contributing to both the alternating pattern of speeding up and slowing down during distance freestyle events and the negatively affected 50-m event performances remain unknown, statistical evidence that lane biases are associated with pool type is given by the chi-square tests of independence. Lanes were more likely to have significant direction effects in the distance freestyle events in temporary swimming pools than in permanent ones. Of the lanes analysed in temporary pools, 42 of 60 lanes (70%) were shown to have a direction effect during distance freestyle events, while half that percentage (35%) were shown to be biased in permanent pools. Additionally, the 50-m splits in the distance freestyle events were more likely to be faster towards the finishing end than away from it in temporary pools than in permanent pools; this occurred in 16 (27%) of the 60 lanes in temporary pools and in 1 (1%) of the 84 lanes in permanent pools. While the association between the categorical variables here does not establish causality, it does provide statistical evidence that lane biases at elite-level swim competitions are associated with the type of pool in which the competition takes place.

At present, it is only possible to speculate as to why lane bias might depend on pool type. Personal communications with pool design experts suggests a pool's hydraulic design specific to how water is returned upon filtering and sanitising may contribute to the production of currents in pools

(Counsilman-Hunsaker, 21 September 2015). For example, total flow through the main circulatory pump, the proximity of inlets to the main pump, pipe diameter serving inlets, the number and location of inlets and direction of water flow into the main basin can all contribute to generation of currents. While true for any pool design, temporary pools have traditionally limited the location of water return inlets to the pool's side and end walls, excluding the entire pool floor. These inlet locations, combined with a reduction of inlet quantity, can result in an increased flow of water through each inlet, potentially leading to stronger water currents. Unfortunately, since temporary pools are deconstructed immediately following competitions, it is not possible to measure the effects of their designs on the biased outcomes presented herein. Regardless, the greater prevalence biased lanes in temporary pools concerns not only the competitive fairness within a competition, but also the ability to compare athlete performances between competitions.

The 2007 World Championships were unique in that swimmers in *all* lanes were shown to have been negatively affected (Table I), a result that may threaten competitive fairness between competitions. If one assumes water current existed during competition, then theoretically, in the distance events, the time lost swimming against the current would have been greater than the time gained swimming with the current. This should have resulted in a worsening of performance outcomes for each lane. An analogue for this is the effect of wind on 100-m running times in which analytic models agree that the time lost when running against a headwind is greater than the time gained when running with an equal magnitude tailwind (Dapena & Feltner, 1987). Relevant to the current study, perhaps, is the precedent within Track and Field, whereby a maximum allowable wind velocity of 2 m/s is agreed upon as the threshold ensuring that record-setting performances are not wind aided. It may be that maximum allowable water currents and accurate procedures to measure them are needed in swimming to ensure fairness within and across competitions.

Within competitive swimming, and also of relevance here, is the precedent of limiting technology when it can be shown to bias performances. The body suits that were introduced in 2000, and subsequently became nearly ubiquitous, were shown to cause a dramatic improvement in elite-level swim performance (specifically in 2008 and 2009), with estimated mean performance gains of 0.3–1.2% (Berthelot et al., 2010). These and other authors suggest that the rate of improvement in the performances of the top 10 swimmers decreases from year to year and does so at a predictable rate. When the world's best performers through this time span were swimming significantly faster than an analytic model predicted, researchers concluded that newly introduced swimsuit technology biased elite-swim performance (Brammer, Stager, & Tanner, 2012). Unequal access and legal issues pertaining to sponsorship contributed to the sport's governing body, FINA, to restrict high-tech swimsuit use beginning in 2010. Policies regarding the physical properties of the suit material and the extent to which this material could cover the swimmer were introduced and subsequently enforced. Importantly, within the current study's findings, performance hindrances of 0.5–0.9% were observed for 50-m events, which are of similar magnitude to the estimated effects on performance by suit technology. Additional competition regulations need to be introduced that address this issue as a means to eliminate a correctible bias. Presently, the only mention of water currents exists within FINA rule FR2.11, in which it is stated, "inflow and outflow is permissible as long as no appreciable current or turbulence is created."

Summary & conclusion

Prior analysis of performance data from the 2013 World Swimming Championship revealed that the swimmers' performances were affected by their lane assignment (Cornett et al., 2015). To extend these findings, the present study was designed to determine whether or not there is evidence to suggest that other elite-level swim competitions were similarly affected. In 5 of the 17 competitions analysed, evidence is provided showing that swimmers were faster in a majority of lanes in one direction as compared to the other during the distance freestyle events. Further analysis of the 50-m events at these 5 competitions indicates that these performances were affected in a manner consistent with the direction effect shown to exist during the distance events. Specifically, when swimmers were determined to be slower when swimming towards the finishing end in the distance freestyle events, 50-m performances were similarly inhibited. The most plausible explanation for these findings is that water currents were present in the pools during the competitions.

In many cases, because the pools were built specifically for the competition and then taken apart immediately afterwards, it is impossible and/or unrealistic to test the swimming pools for water currents. Evidence generated from competition results, however, suggests that lane biases at elite-level swim competitions occur more often in temporary pools than in permanent pools. Critical details of pool design, such as water inlets, gutter design, water depth or other aspects of temporary pool construction will have to be carefully scrutinised in order to eliminate water current as a factor in affecting competitive swimming outcomes. In the short term, it would appear that it is the responsibility of those that govern competitive swimming to (1) identify an accurate and valid means of measuring water currents and (2) specify a maximal water current threshold above which a competition cannot be considered unbiased or valid. An analogous precedent exists within Track and Field whereby wind velocity is measured during competition and record performances are only certified (or not) depending upon established wind velocity thresholds. We strongly recommend the immediate establishment and implementation of analogous provisions in the sport of swimming.

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