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Endurance Profiles of German Elite Swimmers over Three Decades

Entwicklung von Ausdauerleistungen deutscher Spitzenschwimmer über drei Jahrzehnte

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Summary

- **Evaluation and improvement** of aerobic capacity is an essential aspect of performance diagnostics. At the German Swimming Association, the 'Pansold' incremental step-test has been well established and standardized since the 1980s. The unchanged test protocol and the consistent use on all squad members has the advantage of comparability of huge datasets over 3 decades.
- **The aim of this study** was to compare the Pansold-test results of the current German national swimming team with the results of former national teams. We analyzed the progression of the main parameters of the lactate-performance-curve for all and single disciplines, and looked for differences between sprinters and distance swimmers, as well as gender differences.
- **The results show** that the current German national swimming team is faster than former national teams, but this seems to be achieved with higher energy expenditure. The maximum mean swimming speed rose significantly over the period studied, and the maximum lactate level increased on average by 2mmol/l. Conversely, the value for aerobic capacity decreased significantly in almost all disciplines. Men and sprinters reach higher peak lactate levels, but seem to have lower aerobic capacity with a flatter lactate performance curve than women and distance swimmers. Overall, the findings demonstrate considerable progressions in German high-performance swimming over the last 3 decades which might depend on higher training volumes in former times.

Zusammenfassung

- **Im Leistungsschwimmsport** führen die vielen unterschiedlichen Schwimmlagen und Streckenlängen zu differenzierten Anforderungsprofilen. Die Bestimmung und Verbesserung der Ausdauerleistungsfähigkeit ist ein wesentlicher Bestandteil der Leistungsdiagnostik. Ein seit Jahren standardisiert durchgeführter Ausdauertest im Deutschen Schwimmverband ist der Stufentest nach Pansold. Der unveränderte Testablauf mit gleichen Auswertungsmethoden und die konsequente Anwendung des Tests auf alle Kaderathleten ermöglichen eine langfristige Vergleichbarkeit über mehrere Jahrzehnte auf der Basis umfangreicherer Datensätze.
- **In dieser Untersuchung** wurden die disziplinspezifischen Pansold-Testergebnisse der aktuellen Nationalmannschaft mit den Ergebnissen früherer Nationalteams aus den 1980er- und 1990er-Jahren verglichen. Der Vergleich der Hauptkenngrößen der Laktatleistungskurve zeigt, dass die heutigen Schwimmer zwar schneller sind, allerdings scheinen sie mit höherem energetischem Aufwand zu schwimmen.
- **Die maximale Schwimmgeschwindigkeit** wurde über die Jahre signifikant verbessert, genauso wie das maximal im Test erreichte Laktat im Durchschnitt um ca. 2mmol/l anstieg. Im Gegensatz dazu sinkt der $P_{4,0}$-Wert, als Ausdruck der aeroben Leistungsfähigkeit, fast in allen Disziplinen signifikant, genauso wie die maximale im Test erreichte Leistung abnimmt. Außerdem wurden Unterschiede der Kenngrößen von Sprintern und Mittelstreckenschwimmern, sowie Geschlechtsunterschiede bestimmt. Männer und Sprinter erreichen im Mittel höhere maximale Laktatwerte mit einer flacheren Laktat-Leistungskurve und geringeren $P_{4,0}$-Werten als Frauen und Mittelstreckenschwimmer. Die langfristigen Veränderungen könnten ihre Ursache in größeren Trainingsumfängen in früheren Jahren haben, die Geschlechts- und Distanzunterschiede sind möglicherweise auf die größere Muskelmasse der Männer und Sprinter zurückzuführen.

KEY WORDS:
Swimming, Pansold-Step-Test, Lactate, Diagnostics, Aerobic Capacity

SCHLÜSSELWÖRTER:
Sportschwimmen, Stufentest nach Pansold, Diagnostik, Laktat, aerobe Kapazität

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Introduction: Idea of the Study and Research Question

In competitive swimming, various specific tests are conducted to determine athletes' performance. To assess different aspects of the athlete's endurance capabilities while swimming a number of incremental step-test protocols have been developed and used in various countries (1, 7, 19) for quite some time now. At the German Swimming Association (DSV), the Pansold-step-test has been established as a standardized procedure since the 1980s. Every national DSV squad member has periodically to undergo this multi-stage test in water.

In this study, we compare the data for sprinters and long distance swimmers, as well as differences between genders. Furthermore, we use a unique set of standardized longitudinal data for the same test. ›

Table 1

Test procedure of Pansold-test: 5 stages with increasing intensity and pre-scribed break durations.

STAGE	NUMBER OF INTERVAL	LACTATE GOAL	% OF CURRENT MAX. SPEED	INTERVAL BREAK	STAGE BREAK	TIME OF MEASUREMENT FOR LACTATE
1	3	2-3	80	1 min	3 min	immediately after run
2	2	3-4	85	1 min	3 min	immediately after run
3	1	4-6	90		5 min	after 1 min
4	1	6-8	95		20 min	after 3 min
5	1	max.	100			1, 4, 7, 10 min

Table 2

Anthropometric characteristics of analyzed swimmers in SP3.

	N	AGE	HEIGHT	WEIGHT	BMI (KG/M^2)
Male	193	21,0±3,9	191,4±4,7	86,0±6,4	23,5±1,5
Female	194	17,9±4,1	176,6±6,6	64,3±6,4	20,6±1,6

The combination of historical published data and new collected data allow a comparison of athlete's results over more than three decades.

Problem and Aim

Performance Testing in Swimming

Different distances and strokes require different performance structures in swimming. There are no current requirements profiles for the modern era, but some recent authors give a global overview (12, 18). Most sports scientists agree that physiological properties are essential prerequisites of swimming performance, and that distances between 50 and 1500m draw on a combination of different energy stores (7, 12, 13). However, there are conflicting views about the distribution of energy supply for single distances. Rodriguez (13) published a table with suggested relative contributions of energy systems from different authors. The values differ greatly: for example, at the 200m distance, from 2-30% phosphagen, 25-65% glycolytic and 5-65% aerobic. For 50 to 200m races, anaerobic glycolysis seems to be dominant, nevertheless, aerobic capacity is considered a basic prerequisite for all disciplines in swimming (4, 7, 12, 13).

A widespread and well accepted method for the measurement of energy metabolism is to test for the concentration of blood lactate. Maassen and Schneider (6) describe concisely several factors, which can - apart from the work load - influence the lactate values: muscle mass, kind of recruited fiber types, nutrition and regeneration. Hence, diagnostics should be conducted in standardized form and preferably under laboratory conditions. Field tests are often preferred method in assessing sport-specific work load and movement structure since laboratory testing is neither possible nor appropriate. The Pansold-test combines the advantage of the swimming specific load structure and standardized field conditions. The resulting parameters provide information to assess the aerobic and anaerobic capacity, and to make recommendations for the athlete's training control.

To highlight discipline specific differences we first want to illustrate how the results of gender and distances vary and since our data base allows longitudinal comparison, the goal of this study is to illustrate changes in parameters of performance prerequisites over the previous 30 years.

From observing records, we know that maximum swimming velocity has increased continuously – despite confounds due to withdrawal of swim-suit technologies. Hence we postulate that the parameters for peak performance speed and anaerobic mobilization are increasing over time. On the other hand, given the trend to lower training volumes (16), we assume a decreasing level of aerobic capacity over time.

Test Procedure

In the Pansold-test, swimmers have to undergo five incremental stages in their main stroke and distance – the last one at maximum speed. The test protocol for 100 meters is provided in table 1. For longer distances, in sub-maximal stages, the number of runs and start lactate values are lower. The advised swimming speed in the single stages should result in the intended lactate values. Interval times, stroke frequencies, heart rate, and lactate concentration are measured at each stage.

The results of the step test are evaluated on the basis of a lactate-performance-curve (LPC). Lactate concentration in the blood, depending on intensity, is approximated using the exponential function $y=a*e^{bx}$ with y=lactate (mmol/l) and x=velocity (m/s). Test results with a coefficient of determination for the model fit $R^2<0.95$ are not evaluated.

With this approach six key parameters are identified, which reflect aspects of aerobic and anaerobic energy supply:

- v_{max}: Maximum swimming speed reached in test (m/s).
- L_{max}: Maximum lactate concentration in blood (mmol/l). Expression for 'level of anaerobic lactic energy supply' (17).
- b_{LPC}: Coefficient b of function $y=a*e^{bx}$ is detected as incline of the graph. The higher the value, the steeper the curve.
- $v_{4.0}$: Predicted swimming speed at lactate level 4 mmol/l (m/s).
- $P_{4.0}$: Percentage of best performance at 4 mmol/l threshold. Since 1992, the reference for 100% is determined as the personal record of the previous year in competition. Expression for the 'level of aerobic capacity' (17).
- P_{max}: Percentage of performance in the last stage referred to the personal best in competition.

On basis of these parameters, sport scientists assess the current level of the athlete's performance, determine load zones for basic or anaerobic endurance, and give prognoses for competition. Methodological requests for correct implementation and applicability to practice are low initial intensity, continuous increase of speed, correct length of breaks, and recording of lactate. Moreover, for a sound interpretation of test results factors like preload, glycogen balance, and actual performance level within the cycle of training must be considered. As the diagnostics were always conducted by scientific experts at the Olympic diagnostic centers with obligatory, centrally prescribed specifications, we assume a high quality of test implementation and standardized procedures.

Critical Aspects

Since the development of the Pansold-test in the 1970s, the relevant measurement and scientific methods have evolved

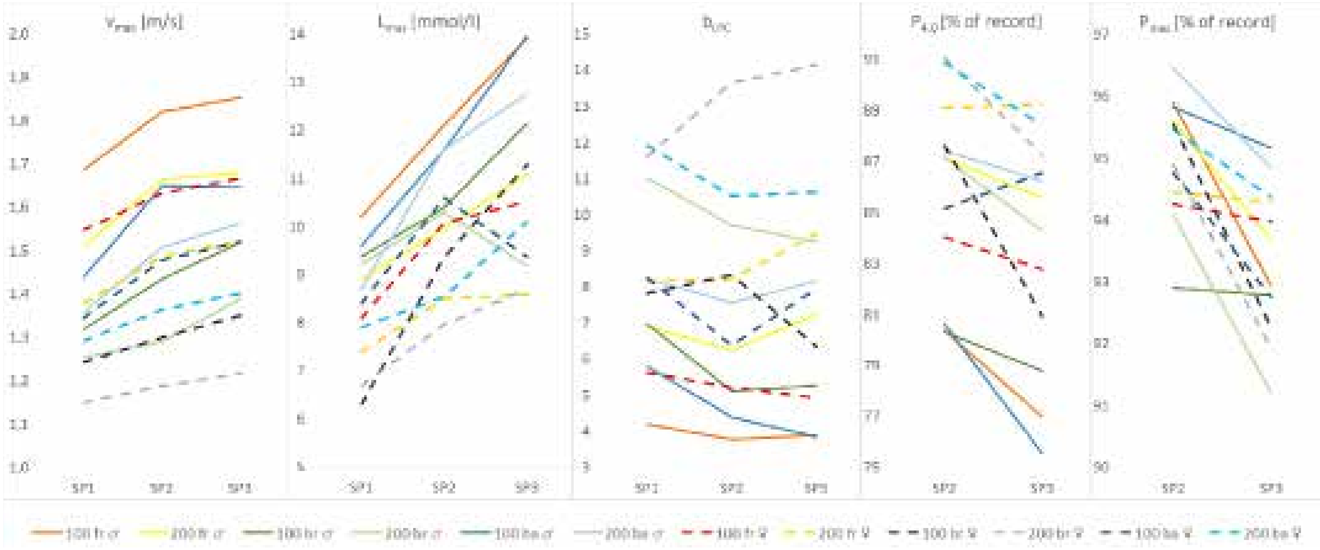

Figure 1

Visualization of general development of main parameters of LPC over three survey periods for twelve disciplines (male solid line, female dashed line).

considerably, especially for lactate measurement (14). Several threshold concepts with different markers for aerobic endurance have been developed but remain controversial (3, 5). Different curve approximations are possible as well as, in general, standards for the assessment of anaerobic performance are discussed controversially (6).

Despite these objections to the procedure used in the Pansold-test, the consistent use of $P_{4.0}$ and of the same mathematical function over the whole period has the advantage of comparability. Zinner et al. (19) criticized the decline of exercise duration and numbers of stages. Nevertheless, the procedure used is more suitable to training and competitive requirements of the athletes rather a time-consuming and expensive MLSS test in a flume channel.

The reliability and validity of the Pansold-test for determining training zones is supported by several investigations (9, 15, 17), which present the connection of load and resulting parameters and recommend requirements for test procedure. As this is the main objective of Pansold-test the validation regarding performance in competition has been neglected. Anderson et al. (2) published typical test-retest errors for time and heart rate lower than 3% and 16% for the L_{max}. Despite these problems, the Pansold-test provides valid indicators for particular aspects of endurance.

Materials and Methods

Sample

Pansold (8, 10) published extensive datasets of over 4,185 step tests for 308 swimmers of the former GDR national squad before 1984, giving means of v_{max}, $v_{4.0}$, L_{max}, and b_{LPC} for each swimming discipline. Rudolph and Berbalk (17) published mean values for Pansold-test parameters aforementioned and in addition $P_{4.0}$ and P_{max} in every discipline of more than 1000 test results for the A-C national squads from 1992 to 1997. Additionally, for the present study, we examined 523 data sets for the current national squad of over 100 swimmers with anthropometric characteristics presented in table 2. The tests were conducted between 2012 and 2015 at different periods during the training year.

These three studies are the basis for a comparison of means at three survey periods (SP1-3) for every discipline and gender. The test procedure and evaluation are standardized for the whole period. All athletes belong to the national DSV squad and have or have had the support of the association. The sample represents the elite of the DSV at the respective SP.

Despite high standards, there are some limitations on a longitudinal comparison. Performance structure may be altered due to doping. Anabolic steroids, for example, might not only induce muscular hypertrophy, but also increase tolerance of extreme training loads and allow quicker recovery times. Therefore, doping may have had an influence on our results, but as all such presumptions are highly speculative, we abide by the given facts. Body composition can also influence endurance parameters. Since these are not given for SP1 and SP2 these effects may not be ruled out in this study. Since the data presents results of regular testing of the national top performers over some years in each SP, some athletes appear repeatedly in the sample, thus violating the assumption of independent measurements. This effect cannot be controlled for SP1 and SP2, so we apply the same sampling strategy by including repeated tests of individual athletes for SP3, as well.

In terms of the numbers of participants, 12 different disciplines are analyzed: 100m and 200m freestyle (fr) / backstroke (ba) and breaststroke (br), for both female (f) and male (m).

Data Processing

To compare parameters over different distances and gender only data of SP3 were evaluated using t-tests. The comparison of means over three survey periods was conducted using a one-way ANOVA with 3-level factor survey period with Bonferroni correction. Due to inhomogeneity of variances, the post hoc test was conducted using the Games-Howell-test. The parameters $P_{4.0}$, P_{max} and personal records are available only from SP2 onwards. In these cases, mean differences between SP2 and SP3 were analyzed by independent t-tests. An alpha of $p<0.05$ was used to rate statistical significance. Pearson correlation coefficient r_p were calculated to investigate relations of LPC-parameters.

Results

Comparison of Gender and Short versus Long Distance Swimmers in SP3

Comparison of LPCs show a typical profile for every discipline and gender.

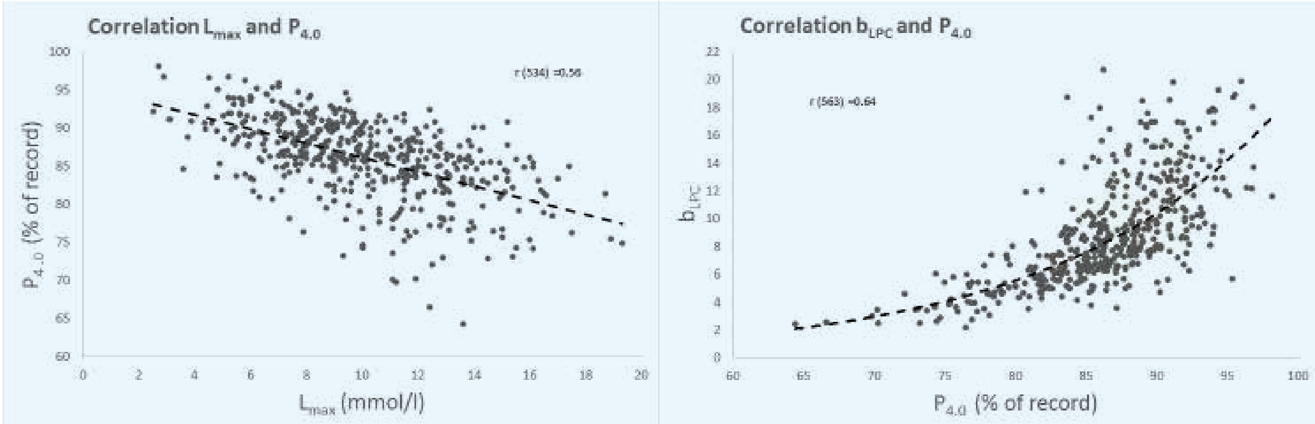

Figure 2

Correlation of parameters of LPC: $P_{4.0}$, L_{max} and b_{LPC}.

- Men have significantly lower b_{LPC}-values than female: male: 7.18±1.99, female: 9.54±3.65 (t_{385}=-7.9, Hed.g=-0.62, p<0.05).
- For the 100m distances there are significantly lower b_{LPC}-values than for 200m distances: male: 100m 4.48±1.04; 200m 7.75±1.65 (t_{191}=-14.6, Hed.g=-0.90, p<0.05); female: 100m 5.76±1.58; 200m 10.85±3.22 (t192=-14.6, Hed.g=-1.39, p<0.05).
- Sprinters achieve significantly lower $P_{4.0}$-values than middle-distance swimmers: male: $P_{4.0}$ 100m 77.6±3.1; 200m 85.6±3.3 (t_{191}=-13.5, Hed.g=-2.08, p<0.05); female: 100m 83.2±3.6; 200m 88.5±2.9 (t_{192}=-9.4, Hed.g=-1.45, p<0.05).
- Male have significantly lower $P_{4.0}$-values than female: 84.3±4.4 vs. 87.2±3.9 (t_{385}=-6.8, Hed.g=-0.74, p<0.05).
- Male reach higher L_{max}-values than female: 11.7±2.9 vs. 9.4±2.3 (t_{385}=8.3, Hed.g=0.59, p<0.05)
- Sprinters reach higher L_{max}-values than middle-distance swimmers: male: 100m 13.2±3.0; 200m 11.4±2.8 (t191=3.3, Hed. g=-0.48, p<0.05); female: 100m 10.4±2.2; 200m 9.0±2.1 (t192=4.7, Hed.g=0.40, p<0.05).

Relation of Parameters

Figure 2 presents the relation of the parameters: There is a decreasing linear correlation between $P_{4.0}$ and L_{max} with $r_p(534)$= -0.56, p<0.001, the higher the aerobic capacity the lower the highest lactate values. There is an exponential correlation between $P_{4.0}$ and b_{LPC} with $r_p(563)$=0.64, p<0.001 – the higher aerobic capacity, the steeper the LPC-curve.

Attempting to understand the correlations between test parameters and performance in competition, we looked for the best result one month before and after the performance diagnostics measured in score points of world record. Like Pyne (11), we could not find correlations of L_{max}, $P_{4.0}$ or b_{LPC} to the competition performance (R^2<0.1).

Development of Test Performances over Time

As presumed in average the personal records in all but one discipline rose significantly from SP2 to SP3 (supplement table 3 online).

A comparison between parameters of the LPC over three measurement periods reveals some consistent findings. The general development of parameters of LPC over time are visualized in figure 1. Detailed results are listed in supplement table 3 (online).

- In almost every discipline, v_{max} rose significantly from SP1 to SP3, e.g. in 100fr male: 1.69±0.16 to 1.82±0.06 to 1.85±0.04 (F=46.7, η^2=0.17, p<0.05).
- On average, across all disciplines the L_{max}-values of men increased significantly from 9.29±2.36 to 10.88±2.72 and 11.66±2.94 mmol/l (F=125.9, η^2 =0.11, p<0.05). This holds for most single disciplines.
- Although mean L_{max}-values of women increased from 7.54±1.98 in SP1 to 9.18±2.65 and 9.40±2.34 mmol/l in SP3, only the SP1 to SP2 values were significant. Similar results are found in most of the women's single disciplines.
- The parameter b_{LPC} tends to be inconsistent in every discipline.
- $P_{4.0}$ decreased significantly in all disciplines from SP2 to SP3 except in 200fr female and 100ba female, even though the swimming speed at 4mmol/l $v_{4.0}$ all but one disciplines increased. In 200fr male $P_{4.0}$ decreased from 87.1 to 85.6 (t_{249}=3.41, Hed.g=0.453, p<0.05), $v_{4.0}$ rose minimal from 1.51 to 1.53 but not significant.
- Missing standard deviations of SP2 allow determination of a significantly falling P_{max} tendency only for 100 and 200fr male and 200br male (e.g. 200br male) t_{75}=3.05, Hed.g=1.21, p<0.05).

Discussion

The results for gender and distance, as well as the correlations of parameters illustrate the different prerequisites in disciplines. Higher $P_{4.0}$- and b_{LPC}-values for 200m swimmers confirm the importance of aerobic capacity for middle-distance swimmers and prove the different performance structure for various distances. Higher female $P_{4.0}$-values support the higher aerobic capacity of women and conform to former results (17). The correlations between b_{LPC} L_{max} and $P_{4.0}$ confirm that lower aerobic capacity relates to higher lactate levels and steeper curves.

Parameters b_{LPC}, and P_{max} depend mainly on the time in training periodization and should be interpreted only in the context of the individual training process. Pansold and Zinner (10) support the hypothesis that b_{LPC} represents the level of force and/or the technical performance. Rudolph and Berbalk (17), on the other hand, find no evidence for this. Due to varying dates in the training cycle, the inconsistent trend in b_{LPC} over time is not surprising. However, the lower values for men and sprinters indicate an influence of force on this parameter.

The long-term results indicate an obvious transition of main parameters of the Pansold-test over time. Increased v_{max} in test as well as higher speed at 4-mmol indicate a better swimming performance of current squad members, which is in agreement with their better personal best. However, the relative values $P_{4.0}$ and P_{max} decreased. The outright swimming speed $v_{4.0}$ got faster, but less than the records. In 200F male records improved by 3.19 seconds, the times at the 4mmol threshold only by 1.14 seconds, which implies that the difference got bigger. If the $P_{4.0}$ is a marker for the aerobic capacity, we could conclude that current German swimmers have less aerobic endurance than in former times, even if the outright times increased paltry. Rising maximum lactate levels support the theory that current athletes have developed their anaerobic qualities, even if we consider that the modified method of lactate testing tends to give minimal higher lactate values in SP1-2 (17). In competition lactate concentrations are approximately 2-3 mmol higher than in testing. The decreasing P_{max}-values indicate that current swimmers approach close to their record only in race and reach even higher lactate levels. However, P_{max} depends on the time lag between test and main competition.

The possible causes for that obvious shift of parameters are various. Even if we find rarely published training protocols of former or current swimmers, especially not over a long period, we may suspect that trainings modalities have changed substantial in the last 30 years. The importance of strength training increased while the training volumes decreased (4). We assume that the higher aerobic endurance in the 1980s is related to the much larger training distances. Similarly, it may be assumed that in the 1990s swimmers still profited from more extensive training at younger age. Furthermore, the increase of lactate levels, especially for men, could be explained not only by a rising velocity. Indeed, more intensive kicking after start and during swimming leads to an expansion of used muscle mass as well as a higher overall muscle mass due to increased strength training could result in a higher lactate production. Missing anthropometric values of former athletes impede verification. An additional effect of strength training is the subsequently earlier and higher activation of FT fibers, which primarily produce lactic acid.

Drawing conclusions from our results for training of contemporary top level swimmers should only be done with caution. Derivations from means are not directly applicable for individuals. The variation of individuals can be greater than variation over years (2). To give meaningful recommendations, the inclusion of comprehensive training documentation would be necessary.

Nevertheless, our study revealed interesting developments in endurance related test parameters and relations between them. Men and sprinters seem to have lower aerobic capacity but reach higher peak lactate levels with a flatter LPC than women and distance swimmers. Furthermore we found considerable progressions in German high-performance sport over the last 3 decades. We believe this study sheds light on the reasons for German swimmers' decline in world rankings and will contribute to the discussion on how best to prepare them for top level competition. ■

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Conflict of Interest

The authors have no conflict of interest.

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