Assessment of the Performance of Timekeepers for Swimming Competitions

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Abstract

In swimming competitions, race times are generally measured using full electronic timing with back-up times provided by semi-manual and manual (stopwatch) timing. The official race time is taken to be the electronic time. However, the reliability of the semi-manual and manual times are important in determining swimmer performance, since either can be used as the official race time, for example, if the electronic time is missing. National swimming governing bodies oversee the training of officials. Timekeeper training includes a practical assessment of performance at manual timekeeping conducted at the poolside. No consistent test criterion is applied to this practical assessment due to the absence of robust reaction time data upon which to base a test. The recent publication of a substantial data set of timekeeper reaction times has allowed the timing characteristics of trained timekeepers to be described by means of a timing profile. Consideration of timekeeper candidates with timing profiles consistent with that of a trained timekeeper and of candidates with significantly different timing profiles enables the properties of practical timekeeping tests to be evaluated. Two tests with good properties are proposed to assess performance at manual timekeeping. Further, a test to assess performance at semi-manual timekeeping is proposed. This is an aspect of timekeeping which has no practical assessment under the current training regime.

Introduction

Electronic timing systems, which remove the human element from the timing process, are used in almost all major sporting events worldwide. Stopwatches and other manually-operated devices may also be used, either as the sole means of recording time or as back-up timing where full electronic timing is used. The timing methods in swimming events are governed by the regulations of the Fédération Internationale de Natation (FINA) (11). Rules in sections SW11 and SW13 are concerned with the related processes of timing and of determining official position and time. Three types of timing are employed: electronic, semi-manual and manual. The electronic time is obtained from automated operating equipment (AOE) with both start and finish managed electronically. The semi-manual timing process is started electronically but is stopped manually by a timekeeper.

For a manual time, a timekeeper in each lane is responsible for operating a stopwatch at the start and finish of the race. In practice the same timekeeper obtains both the semi-manual and manual times in a lane for the duration of a swimming session. The semi-manual time for a swim provides a back-up time if there is a problem with the electronic timing at the finish of the race: for young swimmers this can be due to a light touch on the pad failing to activate the sensor. Manual race times provide vital evidence for competition referees in the event of discrepancies between the electronic and back-up times, in the absence of the primary time, or if the AOE cannot be used. Timekeepers at swimming competitions are normally volunteers yet play a pivotal role in the reliable recording of swimmer performance. The work is demanding: timekeepers are expected to operate both a stopwatch and a semi-manual back-up timer for sessions involving as many as 70 swims over a period of up to three hours in warm, energy-sapping environments, while fulfilling additional tasks such as judging turns, counting lengths completed, insertion and removal of backstroke ledges. In the UK, timekeepers are required to complete the Timekeeper Swimming Officials Course (3) overseen by British Swimming. This comprises "one classroom theory session followed by a practical assessment on poolside" (3). Assessment on the course aims to verify that the candidate has a full understanding of the FINA processes and rules on timekeeping, and that they are able to record times consistent with those of a typical timekeeper in the practical setting of a swimming event. The pool-side assessment includes a test of the candidate's manual timekeeping performance by comparison of a sequence of candidate manual times to those of a trained timekeeper. However, despite the importance of the timekeeping role, little guidance is available on this assessment. The test criterion is not clearly documented and is subject to variability of implementation. Further, there is no test of competence at semi-manual timekeeping. The focus of this work is on setting up practical testing processes to reliably assess candidate timekeeper performance at manual and semi-manual timing. The lack of consistent approach to the assessment of candidate timekeepers can be accounted for due to the historical absence of robust data upon which to base a suitable test. In this work we make use of recently published data from a large number of swims obtained from swimming events (10). The data comprise the electronic and semi-manual times for each swim, with semi-manual times collected by trained timekeepers. Since both timing methods are started electronically and simultaneously, the difference between the two times for each swim is a measure of the reaction time of a trained timekeeper to a visual cue. The distribution of these differences is described as the timing profile of a trained timekeeper.

This timing profile prompts a model of the discrepancy between an electronic time and a manual time recorded by a trained timekeeper. This, in turn, enables evaluation of tests of manual timekeeping: something which has not previously been possible. A useful test is one for which a candidate with timing profile consistent with that of a trained timekeeper has a high probability of passing, and a candidate with a significantly different timing profile has a small probability of passing. Tests are proposed which perform well with regards to these criteria and which are simple to carry out.

We demonstrate that competence at manual timing does not necessarily indicate competence at semi-manual timing, and hence that assessment of performance at semi-manual timing has a valuable role to play in timekeeper training to ensure reliability of timing. A test of proficiency at semi-manual timing is proposed and its properties are provided. Finally, a process of practical assessment is outlined which enables assessment of timekeeper candidates at both manual and semi-manual timing using a single sequence of swims. This has the advantages of being straightforward to administer and of mimicking the timekeeping procedure in swimming events.

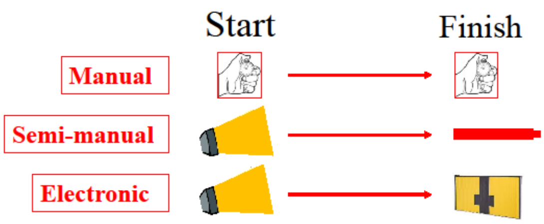
Methods

<u>Timing Procedures</u>

Electronic timing is started automatically, with the start communicated to swimmers and timekeepers via a flash and starting pistol from the starting box, and the finish time determined by the swimmers pressing on touch-sensitive pads at the end of each lane when they complete the race. The electronic time, t_e, is recorded automatically by the timing software in the format m:ss.th, referring to minute, second, tenth and hundredth of a second respectively. The electronic time is taken as the true race time. The semi-manual timer starts automatically in the same way as the electronic timing, but is finished by a timekeeper pressing a button at the end of a stick connected to the timing circuitry. The semi-manual time, t_{sm}, provides a back-up time and is recorded automatically by the timing software and displayed on the computer screen of the electronic timing operator together with the electronic time and saved to file. The computer operator can insert the semi-manual time as the official race time if the primary electronic time is missing.

In manual timing, the timekeeper starts the stopwatch at the flash produced by the start box and stops the stopwatch when the swimmer is seen to touch the pad. Times displayed on the stopwatch are written on a slip of paper. The manual times are not recorded as official times unless the AOE fails and racing reverts solely to manual timing. Manual times are used to confirm semi-manual back-up times in the event of a missing or late electronic time and to resolve place discrepancies. This process is consistent with the British Swimming Referee Training Notes (2), where it is emphasised that the order of decreasing precedence of time sources for a swim are: electronic time; semi-manual time; manual time. The timing methods are illustrated in Fig.1.

Figure 1. A schematic diagram of start and finish processes for manual, semi-manual and electronic timing



Several precautions promote consistency of timing between timekeepers and between races. For all races, the start box is at the same end of the pool as the timekeepers. The start of a race is accompanied by a flash of light and an audible sound from the start box. Timekeepers are trained to activate the stopwatch at the sight of the flash (sound takes about 0.06 s to travel the width of a competition pool). At the conclusion of the race, the timekeepers are required to simultaneously operate the semi-manual (back-up) device and the stopwatch. The advice issued by British Swimming is emphatic on the point at which timekeepers operate the equipment at the end of the race: "When the swimmer is seen to touch the finish wall, the Timekeeper stops the watch. (Do not try to anticipate the swimmer finishing, make sure you actually see the swimmer touch the wall then immediately press the stop button)." (3) Since the semi-manual time has higher precedence than the manual time, timekeepers are trained to activate the stopwatch with the non-dominant hand and the back-up with the dominant hand. The instruction that timekeepers press the stop button of the semi-manual timer once the swimmer is seen to touch the pad should ensure that the semi-manual time recorded exceeds the electronic time. If the electronic time is absent, the semi-manual time is used as the back-up time and will record a slower swim time than if the electronic time had been available. This is consistent with a general sporting principle that a manually-produced time should not be shorter than an electronic one. This principle is incorporated into the test of semi-manual timing proficiency that we propose.

The Data

The data provided by Faux and Godolphin (10) are observational, collected from 16 junior swimming competitions which took place in a 25m pool equipped with AOE in Hampshire, UK during 2017-18. Semi-manual and electronic race times were obtained from 4304 swims. The swimming events involved were swum over 50m, 100m, 200m and occasionally 400m, and were all timed by electronic, semi-manual and manual methods. Electronic times were generated via the AOE operated under the supervision of appointed officials according to FINA Swimming Rule SW11.1 (11). Semi-manual and manual times were all produced by official trained timekeepers, aged between 20 and 60. The swimmers were children, taking part in swimming galas as part of their regular competition schedule. Parental or guardian permission had been obtained for each child to take part and for the race times to be made publicly available.

The final official race times are published online (15) and transmitted to the relevant swimming governing body. The data used to establish the timing profile of a trained timekeeper were obtained from the output data files from the AOE system (10). These files contain both the electronic time and the semi-manual back-up race time for each swim. The files do not identify the swimmer or the timekeeper.

Timing Profiles

For an individual timekeeper, trained or otherwise, and a given swim, the difference between the electronic time, t_e, and the semi-manual time, t_{sm}, recorded by the timekeeper is denoted by $\delta t = t_{sm} - t_e$. The electronic and semi-manual times are started in the same way. The electronic time ends when the swimmer activates the pad at the end of the lane, and the semi-manual time ends when the timekeeper presses the stop button, on seeing the swimmer touch the pad. Thus, δt is the time taken for the timekeeper to activate the stop button on the visual cue of the swimmer touching the pad. The δt values can be regarded as random observations from a distribution, termed the timing profile of the timekeeper. This distribution provides a model for the reaction time of the timekeeper associated with a single activation of a button prompted by an anticipated visual trigger.

The data set described above is used to determine the timing profile of a trained timekeeper. The quantity δt was calculated for each swim and the values were found to be well modelled by a normal distribution with mean 0.11s and standard deviation 0.07s, that is, by the N(0.11,0.072) distribution. Details are provided in (10). A small proportion of negative δt values were observed, indicating that trained timekeepers do occasionally anticipate a swimmer reaching the pad. If all trained timekeepers adhered strictly to the British Swimming guidance not to anticipate the touch, all δt values would be positive. The distribution mean indicates that, on average, when recording a semi-manual time a trained timekeeper stops the back-up timer 0.11s after the swimmer touches the pad. In a study of data from a sample of seven timekeepers, good consistency was found between timekeepers. Thus, N(0.11,0.072) is taken to be the timing profile of a typical trained timekeeper.

The timing profile of a candidate timekeeper is modelled by a normal distribution with mean μ and standard deviation σ, i.e. the N(μ,σ2) distribution. Thus the timing features are characterized by location and dispersion parameters μ and σ respectively. In developing tests to assess performance at manual and semi-manual timekeeping, the aim is to identify tests which candidates with timing profile close or equal to N(0.11,0.072) have a high chance of passing, and candidates whose timing profile differs significantly from this distribution have small probability of passing. The use of timing profiles is intrinsic in identifying the capacity of a test to discriminate between candidates whose performance at manual or semi-manual timing is consistent with that of a trained timekeeper and those who do not meet this standard.

Assessment of Performance at Manual Timing

We first investigate tests for competence at manual timing, since this aspect of timekeeping is assessed in the current training. The actions of starting and stopping the stopwatch to obtain a manual time are both activations of a button prompted by an anticipated visual cue, namely the flash and the pad touch. Therefore, both actions are modelled by the timekeeper timing profile.

A test which is reportedly used in the practical assessment of manual timekeeping, referred to subsequently as M1, requires the candidate to achieve ten consecutive manual times within 0.3s of those of a trained timekeeper. Properties of test M1 can be determined by means of timing profiles. Let t_{mT} and t_{mC} denote the trainer and candidate manual times for a given swim. To pass M1, the times for all ten swims must satisfy -0.3 ≤ t_{mT} - t_{mC} ≤ 0.3. For a trainer and candidate with timing profiles N(0.11,0.072) and N(μ,σ2), the discrepancy between the manual times, t_{mT} - t_{mC}, is modelled by N(0,2(σ2+0.072)). Note that this distribution is independent of the location parameters. Given a candidate dispersion parameter, σ, the distribution of t_{mT} - t_{mC} is known and the probability that the candidate passes M1 can be calculated.

Evaluation of the probability of passing M1 for candidates with different timing profiles provides a measure of the ability of M1 to discriminate candidates who are proficient at manual timing from those who would benefit from further mentoring and practice. We consider candidate timing profiles with arbitrary μ and with σ in {0.07,0.14, 0.21}. A candidate with σ = 0.07 has desirable characteristics for manual timing, termed *typical*. Conversely, candidates with σ = 0.14 or σ = 0.21 have undesirable timing characteristics which we describe as *erratic* and *highly erratic*. For a single swim, the quantity t_{mT} - t_{mC} for candidates with typical, erratic and highly erratic characteristics has distribution: $N(0,4\text{x}0.07^2)$, $N(0,10\text{x}0.07^2)$ and $N(0,20\text{x}0.07^2)$. The probabilities of passing M1 for each candidate type are presented in Table 1. Calculations are conducted using statistical software R version 3.5.0. The probability that a candidate with σ = 0.07 fails M1 is 0.279, i.e. M1 has a Type I error probability of 0.279. Candidates with σ = 0.14 have probability 0.145 of passing. Thus, M1 has a Type II error probability of 0.145 and power of 0.855 with regards to such candidates. To summarise: one in four candidates with desirable typical timing characteristic is expected to fail and one in seven candidates with erratic timing characteristic is expected to pass. This suggests that M1 may not be fit for purpose.

Investigation of tests involving various numbers of swims and criteria for passing prompts an alternative test M2. This is similar to M1, in that manual times recorded by a trained timekeeper and a candidate timekeeper are compared for a sequence of swims.

To pass M2, in a sequence of 20 swims at least 19 candidate times must differ from the trainer time by no more than 0.3s. As with M1, the models for t_{mT} - t_{mC} for the typical, erratic and highly erratic characteristics enable calculation of the probability of passing M2 for each candidate type. Results are presented in Table 1. Test M2 improves on M1 with a Type I error probability of 0.134, less than half that of M1. Further, M2 has higher power to detect candidates with σ = 0.14: the Type II error probability is 0.111 and the power of M2 to detect such candidates is 0.889. For both M1 and M2, the power to detect a candidate with σ = 0.21 is high, since the probability of such a candidate passing either test is very small. Tests using sequences of more than 20 swims which would improve on M2 could be devised, but 20 swims is chosen as a large enough number to achieve an effective test without being so large as to make the test impractical.

We now suggest an alternative test in which candidate manual times are compared directly with electronic times, for a sequence of swims. The difference between an electronic time and a candidate manual time, t_{mC} - t_{e}, is modelled by $N(0,2\sigma^2)$. As with M2, test M3 involves a sequence of 20 swims. Success in M3 is achieved if each candidate time differs from the electronic time by no more than 0.3s. Results are contained in Table 1. Test M3 has a Type I error probability of 0.047, considerably smaller than that of M2. Further, M3 has power of 0.938 to detect a candidate with σ = 0.14.

To summarise properties of the proposed tests: for M2 one in seven candidates with typical timing characteristic is expected to fail and one in nine candidates with erratic timing characteristic is expected to pass; for M3 the proportions are one in 21 and one in 16 respectively. In comparing candidate and electronic times, M3 has advantages over M1 and M2 which compare candidate and trainer times. First, M3 depends on the distribution of t_{mC} - t_{e}. This quantity has smaller variance than t_{mT} - t_{mC} which is associated with M1 and M2, since no account needs to be taken of trainer variability. The smaller variance is reflected in M3 having lower Type I and Type II error probabilities than M2, even though both tests involve 20 swims. Second, unlike the case with M1 and M2, probabilities reported for M3 do not depend on the assumption that the trainer has timing profile $N(0.11,0.07^2)$. If the particular trainer actually has timing profile with σ > 0.07 then the true probabilities of passing M1 and M2 are smaller than the values given in Table 1, and if the trainer has σ < 0.07 the true probabilities are larger.

Table 1. The probabilities of passing practical assessments in manual timing, with competency characterised by the standard deviation of the candidate timing profile

	Candidate Variability		
Test	typical σ = 0.07	erratic σ = 0.14	highly erratic σ = 0.21
M1	0.721	0.145	0.016
M2	0.866	0.111	0.003
M3	0.953	0.062	0.001

Assessment of Performance at Semi-manual Timing

Timekeeper training currently includes no practical test of semi-manual timing proficiency. This omission is surprising given that semi-manual times have priority over manual times (2). We seek a test to parallel M2 and M3 by requiring candidates to achieve a stated level of reliability in semi-manual times for a sequence of 20 swims. Denoting a candidate semi-manual time by t_{smC}, the distribution of t_{smC} - t_e is just the candidate timing profile $N(\mu,\sigma^2)$. Thus, performance in semi-manual timing depends on both μ and σ. A useful test will have high power to detect a candidate with erratic timing characteristic or who has an undesirable reaction time by anticipating the swimmer's touch or by being slow to react. Having investigated various criteria, we propose a test which we label as SM1. To pass test SM1, the candidate is required to obtain a time which is not shorter than the electronic time but exceeds the electronic time by no more than 0.22s, that is $0 \leq t_{sm} - t_e \leq 0.22$, in at least 17 of a sequence of 20 swims.

To establish properties of SM1 we consider three values of the location parameter: candidates with μ = 0.11 are described as *typical*; those with μ = 0.04 as *anticipatory* and those with μ = 0.18 as *slow*. The probability of passing SM1 is evaluated for each of the nine candidate timing profiles with μ in {0.04, 0.11, 0.18} and σ in {0.07, 0.14, 0.21} and the values are given in Table 2. The probability that a candidate with timing profile consistent with that of a trained timekeeper, i.e. $N(0.11,0.07^2)$, passes the test is 0.804. Thus, SM1 has probability of Type I error of 0.196 so that about one in five candidates with a typical timing profile will fail the test. The test has power of 0.872 to detect candidates with a typical dispersion parameter (σ = 0.07), but who are anticipatory or slow. Similarly, SM1 has power of 0.992 to detect candidates with a typical location parameter (μ = 0.11), but who are erratic.

Note that whereas a value of σ below 0.07s is a positive feature, indicating consistency of timing, a value of μ considerably below 0.11s would suggest anticipation of an event, such as the swimmer touch on the pad, and is not desirable since it can result in incorrect ordering of place positions. The requirement that the semi-manual time is not shorter than the electronic time in SM1 is based on the explicit British Swimming instruction that timekeepers should not anticipate the swimmer finishing (3). Test SM1 conforms to the need to avoid back-up times that are faster than the electronic time.

Table 2. The probabilities of candidate timekeepers passing test SM1, a practical test in semi-manual timing, for nine candidate timing profiles

	Candidate Variability		
Candidate Location	typical σ = 0.07	erratic σ = 0.14	highly erratic σ = 0.21
anticipatory μ=0.04	0.128	0.002	0.000
typical μ=0.11	0.804	0.008	0.000
slow μ=0.18	0.128	0.002	0.000

<u>The Assessment Process</u>

For a training environment where electronic timing is not available, test M2 is recommended. Where electronic timing is available, we propose the use of M3 to assess skill at manual timing and SM1 for semi-manual timing. The tests can be administered during a swimming event with no disruption. Further, conducting tests of manual and semi-manual timing concurrently at a swimming event has the advantage of testing the candidate under the same conditions, with respect to task and environment, that they will be required to record times in as a timekeeper. The Coaching Application document accompanying this paper gives guidance on the administration of the tests and includes a pro forma that can be used to record times during assessment.

Discussion

A substantial body of research investigates factors which affect reaction time. Males tend to have faster reaction times than females (6,13). Work on the combined effects of handedness and gender found left handed subjects to have faster reaction times than right handed ones, and that reaction time was faster with the dominant hand (5). Timekeepers are advised to use the semi-manual back-up timer in the dominant hand and the stopwatch in the non-dominant hand (for both start and stop). This advice recognises the greater importance of semi-manual timing due to its use as the official race time if the electronic time is absent. This research is also reflected in our advice for managing the testing of candidate timekeepers. Work on reaction time and age reports a decrease in mean reaction time from the late teens to the early thirties and a steady increase after approximately 50 years of age (6). A study involving sprinters found athletes aged 16-17 to have significantly slower reaction times than older athletes (18). In the UK the minimum recommended age for timekeepers is 14 years, however in practice timekeepers tend to be the parents or guardians of young swimmers and therefore in the 30-55 age range. We do not make recommendations as to a minimum age for candidate timekeepers as the proposed tests will establish the suitability or otherwise of candidates. Reaction time is also affected by, or correlated with, factors associated with lifestyle and environment. Physically active lifestyles are correlated with faster reaction times (13,17). Work on the effect of atmospheric conditions (4) found significantly slower reaction times in temperatures above 30 degrees C. This is typical of a swimming event environment.

With such diverse factors affecting reaction time, confirming a degree of consistency among timekeepers is important. The present study is the first to construct tests of timekeeping underpinned by scientific justification. This is achieved by the concept of timing profile and the specific timing profile, $N(0.11,0.07^2)$, for a trained timekeeper (10). In using data from swimming events to obtain this timing profile, some factors affecting reaction time such as gender, handedness and age are incorporated into the dispersion parameter $\sigma = 0.07$. Other factors are fairly stable by the nature of the data: the temperatures at which the data were collected was fairly consistent; timekeepers are trained to activate the back-up with the dominant hand.

Derivation of the timing profile arose from consideration of the distribution of the δt values which relate to the reaction time on stopping timing equipment at an anticipated visual cue. The tests on manual timing are based on the assumption that the timing profile also applies to the action of starting the stopwatch. The implication of this is that the difference between a manual time and an electronic time, $t_m - t_e$, has zero mean, i.e. that manual times exhibit no bias. It is useful to explore this point. A body of literature compares manual and electronic methods of timing sprints. Some studies, each involving fewer than eight timekeepers, report manual times as being faster than electronic times (8,9,14) and one study, using three timekeepers, reports manual times as being significantly slower (16). In a study of 26 timekeepers, Hetzler et al. (12) find no significant difference between electronic and manual times and suggest that the inconsistency in the literature can be attributed to differences in starting procedures. The study by Hetzler et al. has pertinent features in common with timing methods used in swimming events: the start of the electronic timing was accompanied by an audible signal and visual strobe; timekeepers were instructed to start the stopwatch on the flash and to stop it when the runner was seen to cross the timing gate. The absence of significant difference between electronic and manual times in the study validates use of the timing profile to model both start and finish timing actions of timekeepers in this work. As an interesting aside, we note that whereas a manual race time using a stopwatch should exhibit no bias, a semi-manual race time will be, on average, 0.11s longer. Thus, the indication is that fully-manual timing is likely to provide a more accurate estimate of the true race time than semi-manual timing.

The need for experienced timekeepers to monitor times from AOE and to provide back-up times is reinforced by work comparing the reliability of different automated timing systems in timing sprints. Equipment malfunction and false triggers are reported in processes employing infrared photocell beams and lasers (1,7).

Conclusion

The tests advanced here are not intended as being the final word on assessment of timekeeper performance but are intended to form a starting point for discussion of the assessment process. In the development of tests M2 and M3 to assess proficiency at manual timing, and SM1 to assess semi-manual timing, one focus was to obtain tests with small Type I error probabilities, so that candidates with timing profile close to $N(0.11,0.07^2)$ have a high chance of passing. In development of M2 and M3, the second aim was to obtain tests with high power to detect candidates with timing profile which is erratic or worse, $\sigma \geq 0.14$. When developing SM1, a second aim was to identify a test with high power to detect candidates with either or both $\sigma \geq 0.14$ and $|\mu - 0.11| \geq 0.07$, i.e. a timekeeper who is erratic and/or is slow or anticipatory. We are not aware of any prior practical test to assess skill at semi-manual timing. The approach used in this work could be adjusted to develop tests with high power to detect different levels of divergence from the typical timing profile.

An informal assessment of test SM1 was made at a weekend competition in March 2019. On average, trained timekeepers obtained 2.5 fails in 20 valid races. Thus on average, the timekeepers would pass SM1 which allows up to 3 fails in 20 races. As expected from the data used to determine the timing profile of a typical timekeeper (10), about half the fails were due to anticipating the touch of a swimmer. Elimination of anticipatory timekeeping, as advised by swimming authorities, would mean that SM1 is comfortably passed by trained timekeepers.

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