The Faster, the Better. When the Payoff Depends on Reaction Times in Natural Experiments

(Article begins on next page)

The Faster the Better. When the Payoff Depends on Reaction Times in a Natural Experiment

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Abstract

Studies in experimental economics have recently started using reaction times to better understand the cognitive processes behind decisions. This paper explores an issue that is so far uncovered by the economics literature: whether reaction times respond to incentives. I analyse the outcome of a natural experiment (the behaviour of athletes at the World Swimming Championships) in three steps, where only the (expected) payoff increases from one step to the next. The payoff depends on the time of the race, of which the RT is part. Considering, for each competition, a homogeneous sample of swimmers, the paper shows that RTs decrease as the expected payoff increase. The observed reductions are comparable in magnitude to those observed in other experiments, where conscious/cognitive process are induced (or, at least, present). The paper concludes that a share of the observed RTs is determined through cognitive processes.

Keywords: reaction times; natural experiment; instinctiveness; cognitive processes

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1. Introduction

Recently experimental economists have started to study response times and reaction times. The first are the time spent by an experimental subject to take a decision since they have been requested to take a decision to when it is taken (Rubinstein, 2007). As such, response times are (often) the result of a cognitive process. Differently, reaction times (RTs) are characterise the individual decision processes (Rubinstein, 2007 and 2012) and are considered by some scholars as a proxy of instinctiveness in decision-making (although some evidence in favour of other interpretations exists). They are the time elapsed between a stimulus and the immediate response of the subject (Camerer et al., 2004 and Koenigs and Tranel, 2007). RTs are being widely used in experimental economics, in particular to study pro-social behaviours such as spontaneous giving (Rand et al., 2012)[1], decision making in risky vs. non-risky situations (Brañas-Garza et al., in press), and voluntary provision of public goods (Lotito et al., 2013). This paper aims at studying whether RTs are influenced by cognitive processes, and, in particular, whether they are responsive to incentives. In particular, this paper compares cases in which the RT is very relevant for determining the final payoff with others in which RTs are hardly relevant for the final payoff.

First, I wish to stress that RTs and response times are different. Rubinstein (2007 and 2008) refers to the time elapsing between when an individual is presented a problem and when s/he responds to it. This is what is most often called response time; although it contains a reactive component, this is likely to come (also) from a cognitive process. Some scholars have recently deepened the analysis showing that response times in social dilemmas depend on how much the decision is conflictual for the individual; in particular, the more conflictual the decision is, the

[1] I thank an anonymous referee for suggesting this and the next references. .

longer the individual takes to come to the decision (Evans et al., 2015). However, also in this case, longer response times are associated to longer reflections. The other type of "time" is the time between some stimulus (for example a sound) and the beginning of the reaction to that stimulus. This is generally called reaction time, and is considered the result of an instinctive reaction; this "time" constitutes the focus of the paper. I claim that also the RTs are partially the consequence of a cognitive reasoning and, therefore, the distinction between the two types is only partial, though genuine. This distinction helps to explain why the response times in the cited works of Rubinstein are of much different scale than the RTs used in the present work.

Using data from swimming competition and the RTs at the start of each swim, this paper shows that the athletes are able to partially influence their RTs, shortening them, when their value in terms of the final payoff is higher. This result shows that RTs are (at last partially) determined by some cognitive process, and that they respond to economic incentives. Of course, this outcome does not render the RTs less important in studies focusing on instinctiveness; rather it suggests that some current interpretation of them (see for example Lotito et al., 2013) should be re-thought.

2. Related literature

The idea that RTs provide insights into the process of deliberation prior to making a decision is very old in the psychological literature and, according to Stenberg (1969), dates back to 1868. RTs have been initially taken as a measure of how much the response is instinctive; in particular, the shorter the RT (i.e. the faster the response to the stimulus), the more instinctive the (mental) process that led to the response (Rubinstein, 2007 and 2008 and Kahneman, 2011). In Rubinstein's words: "choices that require more cognitive activity will result in longer response times than choices which involve an instinctive response. Gabaix et al. (2006) find that RTs are longer when people have to choose between similar rather than different alternatives. The proposed interpretation of RTs seems therefore consistent, even if reasoning leads sometimes to a higher payoff than instinct (Arad and Rubinstein, 2012) and sometimes to the opposite result (Piovesan and Wengström, 2009).

Sommer et al. (1990) Jentzsch and Sommer (2002) had already shown that, when an event is expected, the RT is shorter than when it is unexpected, suggesting that cognitive processes (in this case, expectations) can influence RTs. In the present paper, I take a step more, investigating whether RTs can be affected by variations in the payoff of an action. This is of particular interest for economics, since RT is determinant for maximising the payoff in several cases (Dutch auctions, high-frequency trade in the financial markets, skill tests, etc.). For the purpose of this study I use a multi-stage game, where RTs contribute to determine the final ranking (and the payoffs) of the participants. Moreover, at each stage of the game the payoff increases, while all the other characteristics of the game frame remain unchanged.

The economic literature has already considered games, where RTs contribute to determine the payoff. The literature in game theory has extensively analysed this type of games, classifying them in two categories: preemption games and wars of attrition (Fundenberg and Tirole, 1991). Examples of these are Dutch auctions (for an experiment based on them see Cox and James, 2012), and financial trading (see Brunnermeier and Morgan, 2010 for an experiment on this issue). Here the timing of the decision, and therefore the RT to the stimulus (changes the price of the item/security), are crucial for the agent's payoff. The fastest agent is the one who secure the auctioned item or the traded security. Although this is not synonymous of maximizing the payoff (winner's curse in Dutch auctions), who comes late gets nothing or may have to buy at a price different from his best choice. Nowadays, few experiments

The literature in theoretical and cognitive psychology has produced much research focused on the relationship between reaction times and accuracy in responses/choices (see for example Wickelgren, 1977; Meyer et al., 1988 and Bogacz et al., 2006, this last for a theoretical model on the time-accuracy trade-off). These studies confirm what found also in the economics literature: generally, responses that are more accurate require more time, and this last decreases with experience, for a given accuracy rate. This result suggests that cognitive processes influence response times. However, while the final payoff depends on the speed of the response, through accuracy, these results concern response rather than reaction times. Posner (2008) highlights that alertness (which relates to instinctiveness) may be manipulated through neural networks. Although the author does not specify whether cognitive processes are at work, this possibility remains open. Mori et al. (2002) is perhaps the closest work to that presented in this paper; there, the authors use a notion of RTs that is the same as that used here. In their article, the authors study RTs of karate athletes. This framework is somewhat similar to that used in the present paper, as in karate such as in swimming, the final payoffs may depend on RTs (although through different pathways). Their result shows that RTs are faster in more experienced subjects than in the others. This outcome suggests that some cognitive process is at work also when RTs are involved. However, the present work is different from Mori et al. (2002) under some respects. First, they measure the impact of experience (intended as training) on RTs, in a setting where the value of one second in terms of payoff is the same for all the subjects. This is not the case in my setting, where one second is more valuable for athletes swimming short races than for those competing on long races. Second, their cognitive process is based on experience only, whilst in my case the setting of the game (short vs. long races) induces it. Verschuere et al. (2010) run an experiment, where RTs are used to detect concealed information, and compared with the results obtained using a polygraph. The results of this experiment show that RTs are longer when the individuals face probing questions than when the question is irrelevant. This outcome suggests that some cognitive process affects the RTs of the subjects.

In this paper, I claim that, when the subjects' payoff depends on their RTs positively, then the payoff influences the RTs in the aim of maximising the payoff; for example, in sports competitions, people will try to minimise the RT. To test this hypothesis, I analyse the reaction times of swimmers disputing long-course World Championships. This is a natural framework, in which the subjects are not "technically" part of an experiment and have strong incentives to behave "honestly" (after all, they have trained for a large part of their life to get there and dispute that gold medal!). Moreover, they are (self) selected in such a way to constitute a rather homogeneous group (same motivation, same goal, same training, same rules, same environment, and same incentives). The final time in a swimming race is the sum of two components: the RT and the time of the swim. The swimmers calibrate their effort during the swim, observing what the competitors are doing; in this sense, the time of the swim is the result of a cognitive process. Instead, the RT are more instinctive response to the starter's signal, and should not involve any cognitive process. RTs in swimming are part of the total time that determines the final ranking, however their relative contribution to (and therefore their importance for) the total time decreases with the length of the race. RTs may be crucial in determining the payoff in short races: for example in the freestyle 100m finals, the mean difference between the fastest and the slowest RT is 0.21s, while the average difference between the gold and the silver medals for the same distance is 0.19s. If we consider the prize to be the incentive for the swimmers, then they are incentivised to shorten their RTs more in short than in long races.

A last remark is important here: one might claim that the setting of the natural experiment used here activate athletes' attention rather than cognitive processes. However, Gallagher and Schoenbaum (1999) showed that subsystems in the basal forebrain and the amygdala are responsible for both cognition and attention, suggesting that the two functions are somehow interdependent. Courtney (2004) clinically showed that attention and cognitive processes are integrated one into the other. In particular, cognition activates attention, and this last influences the activity of the areas of the brain, which are relevant in the specific situation. Both these articles allow for concluding that the attention stimulated by waiting the starter's signal may be considered as a part of a cognitive process.

3. Data and methodology

The analysis is based on the results of FINA long-course World Championships from 2003 to 2011. These are held every two years and only top-athletes are selected to participate. Although they are of different ages, they all have trained for years and have taken part in several top competitions[2]; therefore, they are used to react to starting signals. All the results are released publicly and freely on the FINA's website after each championship, since 2003. For each stage (heats, semi-finals – where provided by the rules – and finals) of each competition, the Federation discloses names and ages of the swimmers, reaction times, final times and rank, and intermediate times (at every 50 meters turn). Reaction times displayed in the federal official releases represent

[2] However Vantorre et al. (2010) show that reaction times to the start signal do not vary between elite and non-elite swimmers. This renders the results of this paper more generalizable.

the time elapsing from the starting signal to when the swimmer's feet leave the block (Lyttle and Benjanuvatra, 2004).

Let now consider the structure of the competitions. Winning the gold medal requires to qualify for semi-finals first and for the final then. In the first stage (heats) the swimmers compete to secure one of the two semi-finals; this means that one must rank at least sixteenth after the heats. To dispute the final, an athlete must rank at least eighth at the end of the two semi-finals. The rule of distribution of the swimmers between the heats and between the lanes depends on their qualification time. This means that each swimmer competes against athletes of similar ability, and thus the individual performance should be slightly affected by different abilities of the competitors between the stages. The final ranking after each stage includes all the athletes who disputed that stage, it is based only on the final time of each swimmer, and does not depend on the position of the swimmer in the rank of his/her heat or semi-final. These rules ensure constancy of incentives at each stage and that each swimmer observes directly[3] contestants of similar ability through all the stages of the competition. Therefore, the way in which the swimmers are sorted in the heats and in the semi-finals does not affect strategies and performances through the stages.

According to the federal swimming rules, all the member national federations can enrol at most two athletes for each race; these first run the heats. Then, for short races (i.e. 50, 100 and 200 meters) the best sixteen swimmers at that stage gain access to the two semi-finals[4]; athletes swimming long races (400, 800 and 1,500 meters) access finals directly after the heats. Eventually

[3] Each swimmer observes the seven competitors s/he is in the poos with.
[4] The regular swimming pool for competitions is divided into eight lanes.

the eight best semi-finalists (for short races) or the eight best performers in the heats (for long races) contend for the gold medal.

The swimmers are allocated to the eight lanes of the pool according to their times in the previous step (in the case of semi-finals and finals), or to the time in the qualification trials for accessing the Championships (in the case of heats). The rule prescribes that the athlete with the best qualification time swims in lane 4, the second in lane 5, the third in line 3, the fourth in line 6, the fifth in lane 2 and so on. This means that the swimmers are allocated to lanes following a deterministic rule. Assuming that the best athletes have faster reaction times[5], the process of allocation may engender some bias in what observed. For this reason, I rendered the samples analysed comparable, by considering, for each race, only the average RT of the eight finalists. In such a way, the reaction times of the eight finalist swimmers are considered. A possible different approach is to consider the reaction times of the eight best swimmers in each race. However, given also the high and positive correlation between the sample of the eight finalists and that of the eight best swimmers in heats and semi-finals, the results do not change[6]. A further problem is the interdependence between the observations in each race. It is likely to assume that the athletes react to both the auditive stimulus of the starter and to the visual stimulus of the other swimmers' reaction. In other words, it is likely that the swimmers who wait for starting the race on the blocks react also to the movements of the first to start, and this engenders interdependence between the observations in a given race. However, the use of the average RT of the eight finalists for each stage solves the problem of interdependence.

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[5] This is actually the case: especially in short races, the time differences at the end of the race may be smaller than the differences in reaction times between athletes. Hence, a swimmer may end first and another second just because the first was faster to react than the second was. In other words, the placement in the final rank depends also on the reaction time. Consequently, considering only the fastest eight swimmers reduce biases that may arise from different starting techniques, or different abilities to react.

[6] For brevity sake, the results for this sampling approach are not shown, but they are available upon request.

At this point, the means so calculated can be compared. In particular, for short races six comparisons are possible: across distances RT in each stage (heats, semi-finals and finals) are compared considering two consecutive distances in a time (i.e. 50m vs. 100m; 100m vs. 200m); then for each distance RT in heats vs. RT in semi-finales, RT in semi-finals vs. RT in finals and RT in heats vs. RT in finals. For long races, the same comparisons are performed, except for those involving semi-finals (that are not provided for these distances). The first set of comparisons allows analysing how reaction times change as the race distance varies (and therefore the value of an early reaction decreases); the second set shows the variations in RTs when the highest payoff increases going from qualification for the next stage to the gold medal. However, differences detected between different distances may be simply due to different trainings and approaches to the specific competition; in other words, since the value of a short RT decreases with the swimming distance, in their preparation the athletes who train for short races may focus more on RTs than the athletes who train for long races. This should not be the case when a given distance is considered, as the value of a short RT is constant across all the stages of the competition. Therefore, the comparisons between stages of a same competition are more robust and more informative than those between distances.

Reaction times decrease with practice and training (Blanksby et al., 2002), however any difference in this respect between subjects disappears when they all constantly train (Räty et al., 2002). For this reason, I selected only top athletes, and checked whether the RTs are different between different age groups (assuming that older swimmers have been training for more years). The correlation between age and RT is always extremely low (never larger than -7%) and never significant, witnessing that at the level of world championships, the training is no longer able to improve the RT of the swimmers, and therefore differences in age between the athletes do not matter in the present analysis[7].

Following Brañas-Garza et al. (in press), I will also give a graphical representation of a sub-sample of the data in three figures, aimed at offering a visual synthesis of the results. In particular, the figures will show cumulative density functions of RTs in different competitions, and will therefore allow for analysing the data in the light of stochastic dominance.

4. Results

The results are presented in three tables: the first (Table 1) compares the average RTs between different distances for a given step (heats, semi-finals, finals) of a competition across distances; the second (Table 2) reports the RTs between the different steps of a competition for a given distance. The third table presents panel estimates for the finalists in all styles (first two columns) and for the finalists in freestyle only (third and fourth columns).

Table 1 shows that the RTs grow with the distance to swim, that is as the share of the RT in the total time of the race shrinks more and more. However, this might just be due to different trainings: since RT is not important over long distances, then the athletes who run these distances do not work on reducing their RTs, in contrast with the swimmers who train to swim short distances, for which the RT represents a relevant share of the total final time.

Table 2 compares the RTs between the different steps of a competition for a given distance. Here the figures show that the average RT decreases significantly from heats to semi-finales and from these to finals for almost all the distances swam. This suggests the existence of

[7] Should the opposite have held, the presence of very young swimmers in some competitions may have biased the results.

some psychological mechanism that renders the athletes quicker to react to the starter's signal, as the prize of the race increases from just qualification to the gold medal. The result is interesting, as it reveals that, while RTs may well be a measure of how instinctive a response is, they appear to be influenced by the frame of the game. In other words, when the RT concurs to determine the payoff, then the individual is able to influence it voluntarily. RTs seem to have two components: one strictly instinctive and another cognitive. Given the small reductions observed in RTs, the first component appears much larger than the second does. However, the reduction due to the psychological component is big enough to be of some value for the athletes who swim short distances.

It is also noteworthy that the gains in RTs are on average very small, although sufficient, to modify the final ranking in some cases. For example, considering 100m competitions, in 16.8% of cases the average reduction in the RT between heats and finals (which is about 1.5 hundredth of second) is larger than the time difference between the gold and the silver medal. That figure reduces to just 5% if the competitions over 200m are considered, and converges to 0 for all the longer distances. Nevertheless, the RTs decrease significantly in all the competitions, but 800m freestyle, considered here. This suggests that the idea that "the faster the better" prevails on other rational considerations about the actual value of the reduction in the RT. A possible reason why the reductions in RTs are as small as observed is that the swimmers may be risk averse. Leaving the starting block twice before the signal entails disqualification, therefore the willingness to reduce the RTs may be compensated by the worry of disqualification, thus resulting in small reductions in the RTs[8]. Nevertheless, the value of the prize is larger in finals than in heats and semi-finals; as a consequence the athletes may also become more prone to take risks in finals than

[8] This is consistent with Rubinstein (2012), who often finds a negative correlation between the RT and the probability of making a mistake, when the notion of a mistake is a clear cut.

in the other stages of the competition. In other words, the shorter RTs in finales may result from a cognitive process that induces the swimmers to accept higher levels of risks, given the higher remuneration of winning a final than any other stage. Analogously, investors are ready to buy risky securities that pay high returns. That the reduction of risk aversion is cognitive is shown by the absence of any statistically significant reduction in RTs in long-run swimming competitions. There the athletes know that, differently than in the case of short-run competitions, any small gain at the start will have no effect on the final ranking. As a consequence, the swimmers are not ready to take more risk, what reflects in RTs that do not decrease between heats and finals.

The figures in Table 3 provide further substantiation for the previous conclusions. In particular, they show that RTs are shorter in shorter races (the coefficients are significantly increasing with the length of the race). In addition, RTs are shorter in finals than in heats, as the magnitude of the coefficients shrinks from the first to the second. These figures confirm that RTs are shorter, when they are more valuable in terms of the final payoff, i.e. in shorter races and when the athletes are swimming the final. Interestingly, Table 3 shows also that older swimmers are faster to react than younger swimmers in heats, while the opposite is true in freestyle finals and the effect of age is not statistically significant in the whole sample. An ancillary ordered probit regression shows that the final ranking in finals does not depend on age. This seems to suggest that the more experienced swimmers (i.e. the older) trade off the ability acquired through experience and the fastness in reacting to the starter’s signal; short RTs are indeed risky, as false starts may be penalising. This possibility reinforces the interpretation of the observed pattern of RTs in terms of being partially due to cognitive and voluntary processes rather than to instinct only.

Consider now the cognitive component of the total time. This is not interesting *per se*, as this time does not represent the time of a cognitive process, but rather it is the result of this process. However its variations are the consequences of a cognitive process, either because the swimmers put more effort in the final than in the heat (since the competition is for the medals and not just for qualifying), either because at least one put more effort and the others emulate that one or because of both. The data do not allow for choosing between these possible interpretations; however, all these possibilities are not mutually exclusive and do not change the interpretation of the results.

Let now consider another interesting outcome, which results from the figures presented in Table 3 and supports the cognitive interpretation of the reduction in the RTs. Given that, while swimming in the pool, the athletes calibrate their effort considering the performance of the competitors and the goal of the race (i.e. qualification or medal), and given that swimming faster entails more effort, then the reductions in total time likely result from a cognitive rather than from an instinctive process. A main observation emerges: the order of magnitude of the reductions in RTs and total times is the same: around (or less than) one percentage point. Jentzsch and Sommer (2002) obtain an average reduction in RTs between 0.68% and 1.03%[9], when cognitive processes are activated by passing from unexpected to expected stimuli. This figure is consistent with those found in the analysis presented in this paper; it is noteworthy that cognitive processes (that induced in Jentzsch and Sommer's paper and that induced during the swim competition) lead to time reductions, which are very close to that detected in the swimmers' RTs. This similarity supports the interpretation that the reductions in the swimmers' RTs are the consequence of a cognitive process, rather than of some other instinctive mechanism. Now, the only change in the

[9] Jentzsch and Sommer (2002) propose two experimental treatments; the reductions in the RTs are different, depending on which treatment is considered.

framework between the different stages of a swimming competition is the value of the individual position in the final ranking (qualification in the case of heats and semi-finals and medals in the case of finals). Therefore, it can be argued that the conscious process that leads to the observed reductions in RTs is led by the increase in the payoff at each stage of the competition.

A visual synthesis of the results so far presented is offered by Figures 1, 2 and 3. The first shows the cumulative density functions (CDF) of RTs, when all the finalists in 100m races are considered and presents a first CDF that portrays RTs in heats and a second that depicts RTs in finals. The former stochastically dominates the latter, confirming that RTs are shorter in finals than in heats. Figure 2 presents the same CDFs as Figure 1, but here the sample is restricted to the swimmers who reached the finals in 100m freestyle competitions. Here the stochastic dominance of the CDF for heats over that for finals is even more evident than before, strengthening the previous result (at least for what concerns freestyle competition over 100m). The last figure (3) presents three CDFs; all of them are for freestyle competitions over different distances: 100, 200 and 400 meters. The stochastic dominance of CDFs for longer races over those for shorter is patent. Figure 3 shows that RTs decrease with the length of the race, i.e. as they become more valuable in terms of final payoff.

Last but not least, I would discuss a problem highlighted in section 2: swimmers may react to the movement of some other contestant. This reaction, of course, would not be cognitive, but instinctive. Let start by assuming that all the swimmers but the first-to-move react only to the movement of this latter. The results presented here would in any case suggest that the first swimmer to move reacts in shorter times as the final approaches. This would allow for concluding that the cognitive process, which induces the reduction in the RT of the first-to-move, is responsible of the reduction in the RTs of all the other contestants. Indeed the reaction time of the first-to-move reduces on average (i.e. considering the whole sample) from heats to semifinals (from 0.732 seconds to 0.720 seconds – difference significant at 99% level) and from semifinals to finals (from 0.720 seconds to 0.714 seconds – difference significant at 99% level). This suggests that the observed reduction in all the RTs would be anyway determined (also) by a cognitive process (as the RTs of the first-to-move cannot be affected by the reaction to the starter of other swimmers). However, if the reaction to the optical stimulus generated by the first-to-move were the only (or the main) explanation, then we should observe several swimmers to dive in response to a false start. Anecdotal evidence, however, generally suggests the opposite: the swimmers perceive false starts as such and do not leave the starting block[10]. In other words, the visual reaction component, if any, seems to play a minor role in determining RTs. This supports the interpretation of the observed reduction in RTs in terms of a cognitive rather than an instinctive process.

5. Discussion and conclusion

The aim of this paper is neither that of criticising the extant works based on RTs, nor to suggest that their conclusions are not valid. Rather, this paper aims at showing that RTs respond to incentives. I wish to remind once more that RTs seem to present two components: one instinctive and the other resulting from some conscious (say cognitive) process.

In general, the decision maker "chooses" two aspects: an action and a response time. Even if a cognitive process affects the second aspect, the first may still be intuitive. Of course, the two-component vector indeed may be considered non-intuitive if the decision maker chooses to

[10] See for example the final of the freestyle 1,500 m. at the Olympic Games in London, 2012, or Labeid's false start at the 2011 World Swimming Championships. In both cases only one swimmer dives, while all the others remain on the starting blocks.

shorten the response time[11]. However, in the natural experiment presented in this paper all the subjects are required to choose the same action (diving), as the consequence of a predictable and anticipated event (the start signal). In such a case, the action is not totally intuitive, but pre-determined. This does not rule out the possibility that some actions in response to unanticipated events are intuitive: However, the fact that all the subjects have to choose the same action renders any effect of this action neutral from the point of view of the analysis presented in this paper.

The results presented in this show that RTs are sensitive to the payoff of the game and are slightly modified in order to maximise the probability of getting the highest payoff. Apparently consciousness has only a small (tough relevant) effect on RTs; therefore large differences between RTs may still indicate that some decisions involve more cognitive processes than others do. In addition, in the future experimental economists should design and run more experiments, where the payoff depends on RTs. These last are relevant in many economic decisions, and therefore they are worthy to be studied also experimentally.

There may be of course other cases, in which the cognitive process activated by the situation leads to an increase in the RTs of the subjects. This will then depend on which action (i.e. a reduction or an increase in RTs) maximises the payoff for the individual. Therefore, in these contexts, an increase in the (expected) payoff may induce the subjects to take more time for thinking before taking a decision. The data available so far do not allow for testing this hypothesis, which is left, then, for further research.

[11] I wish to thank an anonymous referee for this remark.

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Table 1. Comparison of RTs between competitions over different distances at a given stage (hundredths of second).

Heats										
	50 metres	100 metres	100 metres	200 metres	200 metres	400 metres	400 metres	800metres	800 metres	1500 metres
	72.48	73.71	73.71	75.85	75.85	79.43	79.43	82.79	82.79	84.06
Significance	**		***		***		***		-	
Semi-finals										
	50 metres	100 metres	100 metres	200 metres	200 metres	400 metres	400 metres	800metres	800 metres	1500 metres
	71.98	72.96	72.96	75.36						
Significance	-		***							
Finals										
	50 metres	100 metres	100 metres	200 metres	200 metres	400 metres	400 metres	800metres	800 metres	1500 metres
	70.83	72.18	72.18	74.49	74.49	78.97	78.97	82.59	82.59	82.33
Significance	*		***		***		***		-	

Levels of significance: *90%; ** 95%; *** 99%.

Table 2. Comparison of RTs between the different stages of competitions over a given distance (hundredths of second)

50 metres			100 metres			200 metres		
Heats	Semi-final	Final	Heats	Semi-final	Final	Heats	Semi-final	Final
72.26	71.98	70.83	73.42	72.44	72.10	75.57	74.83	74.49
***			***			***		
	***			**			**	

400 metres		800 metres		1500 metres	
Heats	Final	Heats	Final	Heats	Final
79.43	78.97	82.79	82.59	83.39	82.39
***		-		***	

Levels of significance: *90%; ** 95%; *** 99%.

Table 3. Panel regression estimates (standard errors in parentheses).

VARIABLES	RT in final	RT in heats	RT in final (freestyle only)	RT in heats (freestyle only)
RT in heats	0.814		0.81	
	(0.0149)***		(0.0267)***	
Age	0.000335	-0.00277	0.000868	-0.00171
	(0.000297)	(0.000542)***	(0.000375)**	(0.000897)*
Male	-0.00326	-0.0192	-0.00865	-0.0204
	(0.00200)*	(0.00510)***	(0.00288)***	(0.00815)**
100 m	0.00267	0.00806	0.00758	0.0171
	(0.00274)	(0.00368)**	(0.00396)*	(0.00724)**
200 m	0.00971	0.0219	0.0138	0.0424
	(0.00285)***	(0.00441)***	(0.00402)***	(0.00941)***
400 m	0.0215	0.0248	0.0298	0.0603
	(0.00374)***	(0.00549)***	(0.00451)***	(0.0101)***
800 m	0.0316	0.0568	0.037	0.0805
	(0.00488)***	(0.00761)***	(0.00573)***	(0.0103)***
1,500 m	0.0249	0.0656	0.03	0.0877
	(0.00509)***	(0.00799)***	(0.00498)***	(0.0105)***
Medley	0.00273	0.00927		
	(0.00368)	(0.00649)		
Backstroke	-0.00875	-0.0864		
	(0.00338)***	(0.00637)***		
Breaststroke	0.00595	0.00886		
	(0.00316)*	(0.00713)		
Butterfly stroke	0.00287	-0.00891		
	(0.00313)	(0.00537)*		
Constant	0.114	0.825	0.104	0.788
	(0.0136)***	(0.0136)***	(0.0222)***	(0.0231)***
R-squared overall	0.805	0.319	0.799	0.244
Observations	1,343	1,343	471	471

The data used refer to the swimmers who run both heats and finals.
*** p<0.01, ** p<0.05, * p<0.1

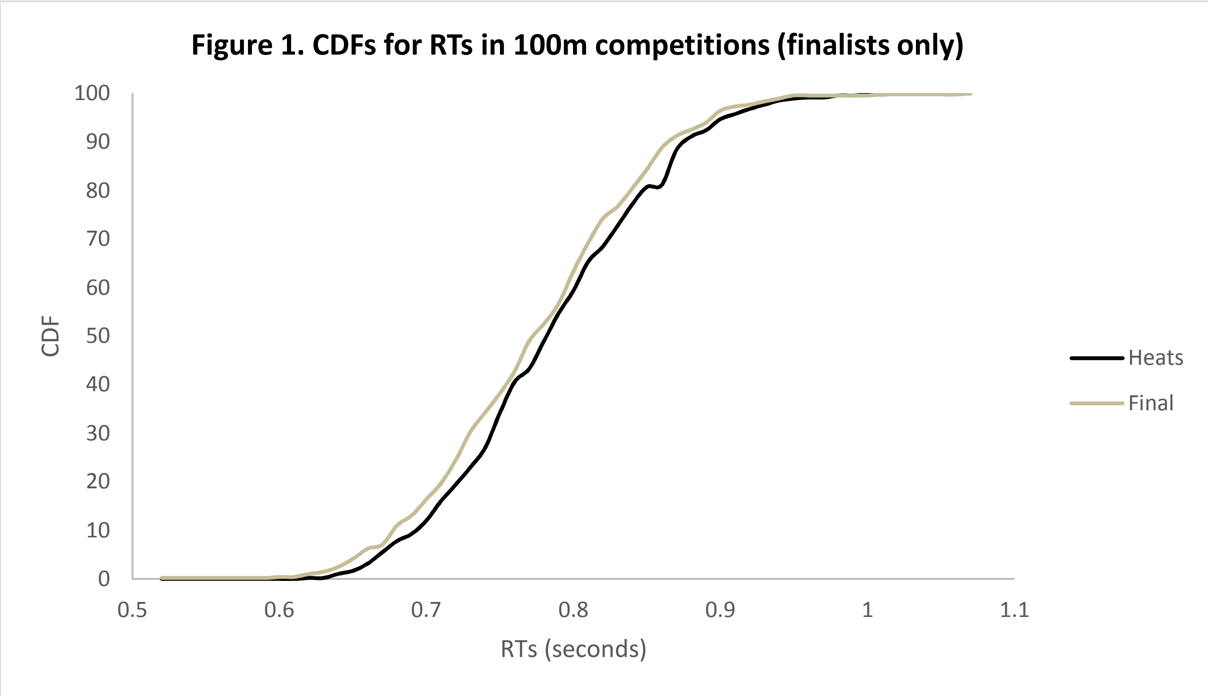
Figure 1. CDFs for RTs in 100m competitions (finalists only)
CDF
100
90
80
70
60
50
40
30
20
10
0
0.5
0.6
0.7
0.8
0.9
1
1.1
RTs (seconds)
Heats
Final

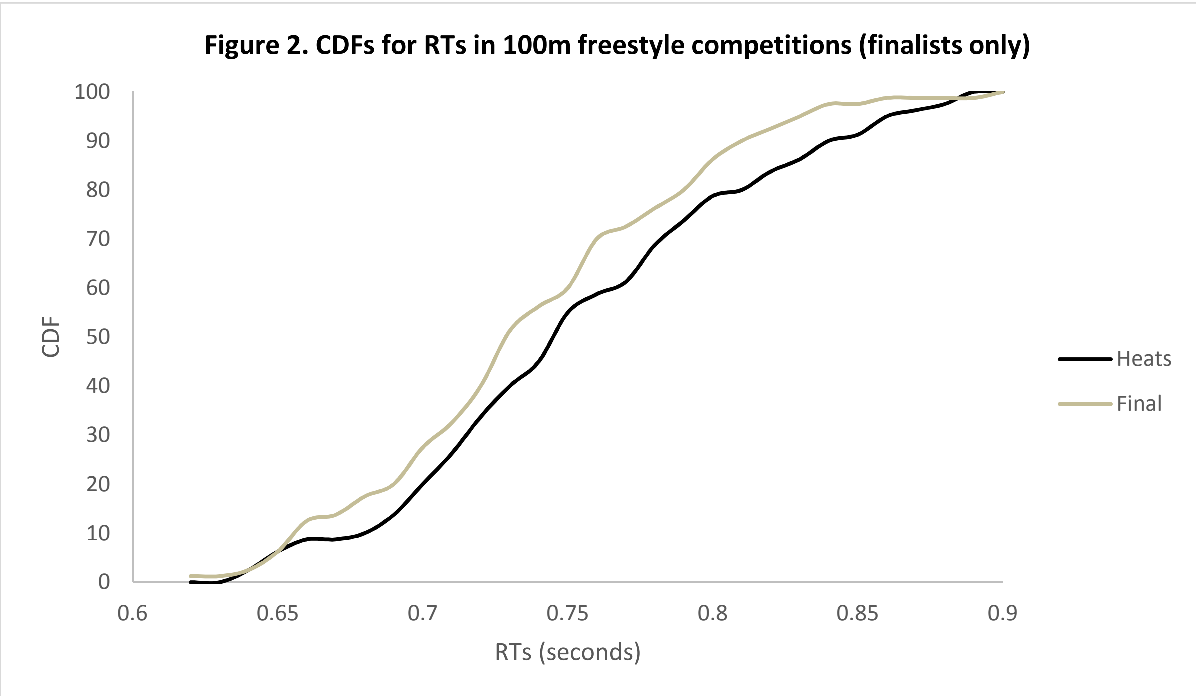
Figure 2. CDFs for RTs in 100m freestyle competitions (finalists only)
CDF
100
90
80
70
60
50
40
30
20
10
0
0.6
0.65
0.7
0.75
0.8
0.85
0.9
RTs (seconds)
Heats
Final

Figure 3. CDFs for RTs in 100m, 200m and 400m freestyle competitions (finalists only)