Does Confidence Enhance Performance? Causal Evidence from Professional Biathlon

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Does Confidence Enhance Performance? Causal Evidence from Professional Biathlon[*]

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Abstract

We analyze the effect of self-confidence on performance using data from top-level professional biathlon competitions. Biathlon combines two independent tasks: cross-country skiing and rifle shooting. We exploit this dual nature of the sport by using weather conditions affecting performance on the skiing track as exogenous variation in confidence on the shooting range. Using round-level data on 254 competitions between 2009 and 2013, we show that the less confident athletes are, the worse their performance is on the shooting range. In particular, we estimate an increase of 0.525 standard deviations in missed shots for every standard deviation increase in our inverse self-confidence measure. Effects for women are estimated to be generally smaller in magnitude and less robust.

JEL Classification: J24, Z2.
Keywords: Self-confidence, performance, biathlon, sports economics.

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I. INTRODUCTION

The relationship between non-cognitive psychological traits and socioeconomic outcomes has recently gained increasing attention by economists (Almlund, Duckworth, Heckman and Kautz, 2011; Borghans, Duckworth, Heckman and ter Weel, 2008). Amongst them, self-confidence (or self-esteem) is considered to be of great importance.[1] Heckman, Stixrud and Urzua (2006) and Judge and Hurst (2007), for example, document that a substantial part of the variation in educational and occupational attainment can be attributed to survey-reported self-confidence. Cobb-Clark (2015) argues that self-esteem along with locus of control are *the* core determinants of individuals' labor market success.

These findings can be rationalized economically with help of theoretical contributions by Bénabou and Tirole (2002) and Compte and Postlewaite (2004). Bénabou and Tirole (2002) show that self-confidence may entail welfare gains through positive effects on personal motivation. They argue that confidence in their abilities may push individuals to undertake more ambitious tasks and be more persistent when facing difficulties along the way. While Bénabou and Tirole treat self-confidence as endogenous with respect to surrounding conditions and the task itself, Compte and Postlewaite (2004) simply assume that higher confidence is associated with a higher probability of success, and derive welfare implications of different states of (self-)motivation from there.

This particular assumption is precisely the point of departure for our paper. In experimental psychology, there is broad consensus that self-confidence and performance are strongly positively correlated.[2] Related studies in this literature also find robust correlations between mood and performance (Baker, Frith and Dolan, 1997; Brand, Verspui and Oving, 1997) as well as stress and performance (Driskell and Salas, 2016). Most of these contributions, however, fail to account for the endogeneity of confidence.

We contribute to the literature by providing first evidence for a causal effect of self-confidence on performance from the field. In particular, we use data from biathlon—an Olympic winter sport which involves two completely independent tasks: cross-country skiing and rifle shooting. In each round athletes have to complete a cross-country trail before they arrive at the shooting range. There the athlete is required to fire five shots, missing targets results in penalties. Our inverse confidence measure is the time an athlete takes for his shots on the shooting range. The faster athletes shoot, the higher we assume their confidence is. Hesitating results in longer shooting time and provides a direct, continuous, and non-bounded measure of lower self-confidence.

An important econometric challenge in this context is the potential endogeneity of self-confidence. Both unobservable confounding variables and especially reverse causality pose serious problems

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[1] Although there may be subtle differences between the two, we treat self-confidence and self-esteem as synonyms.

[2] See, for example, Woodman and Hardy (2003) for a meta-study of 48 psychological papers, or Woodman, Akehurst, Hardy and Beattie (2010) for a more recent contribution. The literature review in Compte and Postlewaite (2004) contains an excellent and comprehensive exposition of the related psychological literature as well.

in terms of identification.[3] We therefore employ an instrumental variables framework where weather conditions are used as exogenous variation in confidence. In particular, we use an indicator for bad snow conditions on the cross-country track as an instrumental variable for confidence on the shooting range. We argue that difficult snow conditions affect shooting outcomes only through their effect on athletes' self-confidence.

Our results suggest that a one standard deviation decrease in self-confidence increases number of missed shots by 0.525 standard deviations, but only for men. For women, we do not find a statistically significant effect of self-confidence on missed shots. In terms of athletes' characteristics, we find that the self-confidence effect is stronger for less experienced males, while we do not find any difference between shooting specialists, running specialists, or generalists. Within-competition dynamics seem to influence the self-confidence effect significantly, as we only find it to be present in the beginning of the competition. Furthermore, intermediate negative feedback does strengthen the relationship between self-confidence and performance. We do not find any effect in competitions where strategic considerations play a large role.

We proceed as follows: In section II we discuss the state of the literature linking self-confidence with performance, in III we provide an overview on the institutional setting. In section IV we summarize our data and the empirical approach we use, and in section V we present our results. Finally, section VI concludes.

II. LITERATURE

In economics the relationship between self-confidence and performance has garnered little attention so far, especially outside the lab. Notable exceptions include Almlund et al. (2011), Heckman et al. (2006), or Borghans et al. (2008), who analyze the effect of non-cognitive skills on performance in general, and Drago (2011) as well as de Araujo and Lagos (2013) who specifically consider the effect of self-esteem on productivity. Using survey data from the U.S., Drago (2011) shows that self-esteem measured in 1980 is positively correlated with wages eight years later. Using the same dataset, de Araujo and Lagos (2013) partly confirm this result. Additionally, de Araujo and Lagos estimate a multi-equation framework and find that the effect of self-esteem affects wages only indirectly through education. A key result is that this indirect effect is more pronounced for males compared to females.

Relatedly, Heckman et al. (2006) employ simultaneous-equation latent variable models and show that self-esteem (amongst other non-cognitive skills) explains a substantial portion of the variation in schooling and labor market outcomes later on. This result is largely confirmed by Borghans et al. (2008). Almlund et al. (2011) compare the predictive power of non-cognitive and cognitive skills on test scores, and find that they are equally important even after conditioning

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[3] See Borghans et al. (2008) for a general discussion on identification problems occurring in analyses on the relationship between non-cognitive skills and performance.

on family background and cognition. In general there seems to be a robust correlation between confidence and academic achievement (Ciarrochi, Heaven and Davies, 2007; Pullmann and Allik, 2008).

Another related strand of the literature considers the relationship between intermediate success and subsequent performance. A common finding of these papers is that perceived success improves subsequent performance—however, most of it is based on laboratory experiments thus far (Gill and Prowse, 2012, 2014). Also closely related is the growing literature on the so-called hot hand effect—that is, an increased probability of further success following intermediate success (e.g., Livingston, 2012). Burton (1988), in particular, analyzes the performance of semi-professional swimmers. While the evidence for an anxiety-performance relationship is ambiguous, he finds a clear positive correlation between self-confidence and performance.

Rosenqvist and Skans (2015) use data from professional golf tournaments. Their empirical results show that players who marginally make the cut (i.e., they survive the first two rounds of a tournament and are allowed to proceed to play in the latter two rounds) significantly improve their performance in the subsequent final round. This would suggest that intermediate success—which is most likely correlated with increased self-confidence—has a positive effect on performance. Distantly related is also the literature on behavioral gender differences in competitive situations. A robust result therein is that men estimate their strengths and advantages higher than women, even if their achievements have to be classified as equal (Niederle and Vesterlund, 2007).

III. Institutions

III.1. Basic concepts of biathlon

Biathlon is a traditional winter sport with long history.[4] Top-level competitions are organized and uniformly regulated by the *International Biathlon Union* (IBU). Biathlon consists of two distinct disciplines: cross-country skiing and rifle shooting. While cross-country skiing requires stamina and power, the challenge in shooting is to fire accurately while being as quick as possible. The firing distance is exactly 50 mts (160 ft). In each shooting round five targets have to be hit with one bullet allowed for each. Half of the shootings are done in prone position, the other half in standing position.[5] In the standing position the target diameter is 115 mm (1.8 in), in prone position the diameter 45 mm (4.5 in).

After each round the time spent on shooting is simply added to the time on the cross-country track. If the athletes misses one or more targets—depending on the type of competition—there are three possible penalties for every shot missed: a penalty loop, an extra minute, or the use of an

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[4] The *International Olympic Committee* recognized biathlon in 1954 and included the sport into the Olympic program in 1960.

[5] Depending on the type of competition the required positions either alternate or are being held in a series.

extra cartridge.[6] The fastest overall time wins. Consequently, all competitors have an incentive to shoot as fast as possible without mistakes. It can be assumed that a high degree of self-confidence and the trust in own achievement will entail a lower resting heart rate of the athlete, thereby influencing shooting performance positively.

III.2. Types of competitions

We consider four different biathlon competition formats.[7] The most traditional competition format is the *'individual,'* which is skied over five loops and athletes starts are staggered by 30 seconds. The total skiing distance is 20 km (6.2 mi) for men and 15 km (9.3 mi) for women. The individual is skied over five loops, including four shooting bouts (prone, standing, prone, standing), with the first one taking place at the beginning of the second round. Each missed target is penalized by a penalty time of one minute. The *'sprint'* format is similar, yet the distance covered is shorter (10 km or 6.2 mi for men and 7.5 km or 4.7 mi for women), it comprises three instead of five laps, and shooting mistakes are penalized via a penalty loop.[8]

In the *'pursuit'* the starting order is based on the results from a previous race (typically the sprint held on the day before). The winner starts first and remaining competitors are separated by the time differences from the previous race. Similar to the individual, it is skied over five loops with four shootings bouts (prone, prone, standing, standing), and mistakes are penalized by means of a penalty loop. Participation in World Cup pursuits is reserved for the 60 top ranking athletes. Finally, in *'mass starts'* all competitors start simultaneously. This format is again similar to the individual, consisting of four shootings (prone, prone, standing, standing) with penalty loops for misses, yet shorter skiing distances (15 km or 9.3 mi for men and 12.5 km or 7.8 mi for women). Due to space limitations at the shooting range, participation is limited to the top 30 ranked athletes in the World Cup.

IV. Data and Empirical Approach

We collect data from the IBU data center at `datacenter.biathlonresults.com`. The data center provides detailed competition reports consisting of in-depth information on each participating athlete's intermediate performance throughout the course of the race. In addition, the data cover geographical information about the track, as well as weather conditions before the start of the race.

Our units of observation are athlete-loop combinations. Each competition format (individual, mass start, pursuit, and sprint) has between three and five loops. In total, we use data from 214

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[6] Only three extra cartridges are allowed. If the athlete is still not able to hit all targets with these extras, a penalty loop must be done for each target which remains standing.

[7] Also team-based relay competitions exist, yet their incentive structures are fundamentally different from the individual disciplines we consider in this paper.

[8] A penalty loop is 150 m (490 ft) long, and takes typically between 21 and 26 seconds to ski.

different competitions on the World Cup level, 16 Olympic events, and 24 World Championship events. This amounts to 73,171 observations on the loop-level. Detailed information on the construction of variables we use throughout the paper can be found in Table 1, summary statistics are provided in Table 2.

Our key variable measuring self-confidence is the time an athlete takes between arriving at the shooting range and firing the last shot in each shooting bout in seconds. The performance outcome is the number of missed shots (out of five possible misses) after each shooting round. In Figure 1 we present the distributions of both variables, and in Figure 2 we plot their unadjusted relationship. The latter indicates a strong positive correlation between shooting time and number of misses. Based on these stylized facts, the empirical model we aim to estimate reads

$$\text{misses}_{iles} = \varphi \cdot \text{confidence}_{iles} + \mathbf{x}_{iles}\boldsymbol{\delta}' + \theta_{is} + \varepsilon_{iles}, \tag{1}$$

where the number of missed shots of athlete $i = 1, \ldots, N$ in loop $l = 1, \ldots, L$ of event $e = 1, \ldots, E$ during season $s = 1, \ldots, S$ is regressed on the athlete's self-confidence prior to the shooting. Additionally, $\mathbf{x}_{iles}$ is a vector of control variables capturing exogenous runner-specific and event-specific characteristics (see Table 1) with associated parameter vector $\boldsymbol{\delta}$, θ_{is} is a vector of runner × season fixed effects, and $\varepsilon_{iles} \sim N(0, \sigma^2)$ is a mean-zero error term. Our main coefficient of interest is φ.

Although we control for a large array of additional covariates possibly influencing confidence and missed shots, there may still be unobserved variables systematically related to both measures, which impairs identification of the model in equation (1). More importantly, reverse causality is a common problem in the analysis of self-confidence and performance (Heckman et al., 2006). Although misses are measured after our confidence variable in time, misses from the last round or the expectation of misses in the contemporaneous round may have an effect on confidence. In order to account for these problems, we use an instrumental variables framework where weather conditions are used as exogenous variation in confidence levels to isolate a causal effect of confidence on performance. Formally, define the instrument as

$$\text{badcon}_e = \begin{cases} 1 & \text{if snowtemp}_e \notin [-5, 0.5] \vee \text{snowcond}_e \subset \{\text{fine grained, powder, soft, wet}\} \\ 0 & \text{else} \end{cases} \tag{2}$$

where snowtemp_e measures the snow temperature at the time of start of event e in degrees celsius, and snowcond_e is a categorical variable with twelve realizations characterizing different snow conditions (see Table 3). Hence, the instrument is a binary variable equal to unity if either the snow temperature is outside the interval $[-5, 0.5]$, or snow conditions are defined as fine grained, powder, soft, or wet, and zero else. The distributions of shooting time for both realizations of the binary instrument are plotted in Figure 3. We see a small increase in shooting time if conditions are defined to be bad.

Snow temperature affects running performance through the friction between ski and ground. If the snow temperature is outside the $[-5, 0.5]$ interval, the snow is wet and heavy, which requires higher effort on the ski track. The same applies to the snow conditions we chose: Fresh snow shortly before or during the race is likely related to increased effort levels on the ski track as well. Both of these factors cause an exogenous variation in skiing time, which will then have an effect on the athletes self-confidence: The faster the skiing track can be completed, the more confident she will be (and vice versa). In section V.2 we show that our results below are robust irrespective of the choice of the temperature interval $[-5, 0.5]$ and the specific snow conditions we define as bad (fine grained, powder, soft, wet). Simply using the snow temperature in continuous form as the instrumental variable yields highly similar results as well. Using badcon_e as an instrumental variable for confidence in equation (1), our first-stage regression model reads

$$\text{confidence}_{iles} = \pi \cdot \text{badcon}_e + \mathbf{x}_{iles}\boldsymbol{\delta}' + \theta_{is} + \zeta_{iles}. \tag{3}$$

Equations (3) and (1) are jointly estimated via two-stage least squares (2SLS), in each case separately for men and women to allow for gender differences in the confidence effect. Apart from runner-year fixed effects, in every regression we control for the quartile of the athlete's starting number, the lag to the previous runner as well as the lead do the succeeding runner after the previous loop, the potential World Cup points the athlete could win if the preceding runner had been overtaken (evaluated *ex post* after every loop), dummy variables indicating whether the weather was foggy, whether the shooting in loop l had to be taken prone, whether loop l was the penultimate loop overall (i.e., the last shooting loop), whether it was a home event for the runner, and whether the event was an Olympic or a World Cup event. Finally, we also control for a set of dummy variables capturing the discipline (individual, sprint, pursuit, or mass start).

For inference we use heteroskedasticity-robust and athlete-level clustered standard errors to account for autocorrelation amongst the observations. The key identifying assumption is that the snow conditions are unrelated to performance on the shooting range. This is reasonable, because neither the snow consistence nor its temperature (as opposed to wind or fog) are likely to be related to how well athletes shoot their rifle. We discuss this issue in more detail in section V.2.

V. RESULTS

The main results derived from pooled sample are presented in Table 4. We estimate a positive and significant effect of lower self-confidence on the number of mistakes: A one second increase in the shooting time results in 0.056 more missed shots (specification 4). In order to allow for different effects across genders, we stratify the sample into males and females. It appears that the overall effect is driven mostly by men, as for women we do not find a significant effect of confidence on performance. In particular, we estimate a positive and significant coefficient of 0.077 for males (spec. 5), yet a very small positive but insignificant effect for females (spec. 6).

Since we interpret a faster shooting time as a proxy for higher self confidence, our estimates do confirm the assumption of a positive effect of self-confidence on performance: Male athletes make fewer mistakes the more confident they are and the faster they shoot. This effect, however, can only be confirmed for male athletes, as there is no causal effect for female athletes' confidence on subsequent performance.

The instrument is tested to be strong in all three samples, yielding values well above 20 throughout. Comparing the IV estimates from columns (4) through (6) to the OLS estimates, we find only a slightly downward biased estimate for the male sample. However, OLS results for female athletes would falsely indicate a positive association for confidence and performance.

V.1. Heterogeneous Effects

So far, our results indicate a positive effect of self-confidence on performance. However, we only observe this effect for male athletes. In this section our objective is to identify the main characteristics which are driving this effect for male athletes. One obvious variable which could influence how self-confidence affects performance is the athlete's experience. Unfortunately, our data do not provide information on how much experience an athlete has. Instead, we observe the age of all athletes and use this as a proxy for experience.[9] In order to test for potential age-related heterogeneity in the effect of self-confidence on performance, we split the male and female samples into age quartiles. The results are presented in Table 5.

We find that the positive effect of self-confidence on performance is only present for less experienced (young) male athletes. We estimate a positive and significant effect for the first and second quartile of the age distribution in the male sample. There is no significant effect estimated for the two quartiles above the median. An explanation for this could be that more experienced athletes are able to perform more consistently on the shooting range, irrespective of the current level of self-confidence. As in the pooled estimations, we do not find any significant effect for female athletes. The instrument, however, is rather weak for women.

Another important factor is within-competition dynamics. The top panel in Table 6 presents the results from estimating model (1) for male and female contests, stratified by intermediate ranks in the observed competition. We do find evidence for a general positive effect of self-confidence on performance, irrespective of the intermediate ranking within the competition. Male athletes in the first half of the leaderboard have a similar positive and significant estimate for the effect of shooting time on shooting mistakes as athletes in the second half. For female athletes, however,

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[9] While age is not perfectly correlated with experience, it still provides a reasonable proxy. This is due to the fact that the typical career path of an athlete in top-tier of professional biathlon is quite common. Athletes who reach the level we observe are typically coming out of youth development programs and make it to the top-level at comparable ages without any career interruptions.

there is no significant effect above or below the median of the intermediate ranking.

During any biathlon season, the relative importance of competitions will vary depending on timing, World Cup positioning, and event location. For example, events in Eastern Russia right before or after Olympic Games or World Championships will be less attractive for athletes to attend. Following such considerations, we split the sample into, what we define as, important and unimportant competitions. The results are presented in the bottom panel of Table 6. As before, we only find a causal effect of self-confidence on performance for male athletes, irrespective of the relative importance of the observed competition.

In addition to the intermediate ranking, another important factor could be the number of previous shooting mistakes. The middle panel in Table 6 shows results for male and female athletes with (1) one or more, and (2) no shooting mistakes before the observed shooting. For men, we estimate a robust causal effect of shooting time on the number of shooting mistakes which is not sensitive to the number of preceding mistakes. Again, we do not measure any significant effect for female athletes.

All biathlon competitions consist of a fixed number of skiing loops. Obviously, the progression of the race should have an influence on the effect of self-confidence on performance in the shooting range. Table 7 gives results for splitting the overall samples for male and female athletes by loop. The results show a strong positive effect of shooting time in the second loop for male athletes. For females we do estimate a significant but somewhat smaller positive effect as well. This suggests that the causal effect of self-confidence on performance is mostly relevant at the beginning of races. For all subsequent our instrument is weak. However, this does not come as a surprising, as athletes might have become accustomed to track and snow conditions.

Biathlon is a sport incorporating two completely different tasks. Both tasks count towards the final ranking, which allows specialization of athletes. In order to classify athletes into shooting and running specialists, or generalists, we proceed as follows: The IBU reports separate rankings for skiing and shooting performances after every event (which do not necessarily coincide with the overall ranking). First, we build quartiles of both the shooting s and running r ranks after each event e, and call them q_e^s and q_e^r, respectively. Second, for each runner i, we calculate means of the quartiles the athlete is in over all events, for instance

$$\bar{q}_i^s = E^{-1} \sum_{e=1 \,|\, i \in e}^{E} q_e^s, \tag{4}$$

which we use to calculate $(\bar{q}_i^s - \bar{q}_i^r)$. If this difference in means between the shooting result quartiles and the running result quartiles is positive, the athlete consistently ranks higher in shooting than in skiing, and vice versa. Third, if the difference in means $(\bar{q}_i^s - \bar{q}_i^r)$ is smaller than -0.3, we classify runner i as a running specialist. If the difference is larger than 0.3, runner i is classified as a shooting specialist. If $(\bar{q}_i^s - \bar{q}_i^r) \in [-0.3, 0.3]$, i is a generalist.[10] Table 8 tabulates the results for different samples stratified by athlete specialization. Once again, we estimate a robust effect of self-confidence on performance exclusively for male athletes across all types of specializations.

V.2. Robustness Checks

One possible threat to identification is that weather conditions may influence the number of missed shots directly through affecting athletes' fitness levels, in particular when they become exhausted as a result of weather conditions making the track more difficult. As a robustness check, we therefore use the time a runner takes between arriving at the firing range and taking her first shot (preparation time) as an alternative measure of self-confidence. For this variables fitness levels should play an even smaller role compared to the total shooting time.

The results for estimating model (1) with the preparation time before the shooting (in seconds) as the dependent variable are provided in Table 9. As for our preferred confidence measure, we again estimate a positive and significant effect of preparation time on the absolute number of missed shots for the pooled sample: a one second increase in preparation time results in 0.013 additional mistakes (column 4). When stratifying the pooled sample by gender, we do again find a positive effect for male athletes (0.014), but no significant effect for females.

Table 10 gives the results for all four Biathlon disciplines separately. It is evident that our main results for male athletes are driven by the individual and sprint disciplines. For mass start and pursuit we do not estimate a causal effect of self-confidence on performance. In addition, first stage F-statistics suggests that the instrument is very weak. This is not surprising, as both disciplines are organized in a substantially different way than the individual and sprint: Athletes in both disciplines are more likely to be affected by in-competition dynamics which leaves little influence for track conditions on self-confidence. As described in section III, mass start and pursuit do not have a starting order with a predefined starting interval. This results in situations where athletes typically will feel the pressure to stay within a group of athletes from the start on. Consequently, shooting and preparation times at the shooting range will less likely be affected by self-confidence, but strategic decisions.

We estimate a very strong causal effect of self-confidence on performance for the disciplines individual and sprint. While both disciplines are highly similar in terms of the general contest format, one potential concern could be that only the shootings at the end—where athletes are typically physically tiring—might be biasing our results. Consequently, we omit the last shootings in the individual and sprint competitions.[11] The results (see Table 11) confirm our baseline results and are. We estimate a positive effect of self-confidence on performance for men in both

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[10] We chose the threshold levels −0.3 and +0.3 to obtain an equal distribution of shooting specialists, skiing specialists, and generalists. Results for other thresholds are available upon request.

[11] In order to able to use observations from the first shooting in the sprint format, we have to omit all lead an lag variables, as the sprint only consists of two shootings.

disciplines. For women, we only estimate an imprecisely estimated smaller effect. These results also indicate that our baseline estimates are not a result of unobserved factors towards the end of contests.

Another potential concern is the definition of difficult track conditions in terms of the chosen temperature interval. Figure 4 plots estimated second-stage coefficients from equation (1) and corresponding first-stage F-statistics for different snow temperature intervals. It is evident that coefficients hardly change when altering the temperature interval. Additionally, we re-estimate our main model with only snow temperature in continuous form as the instrumental variable in Table 12. Coefficients are highly similar to the baseline estimates, thus the categorization of our instrumental variable does not affect our results at all.

VI. Discussion and Conclusion

We provide empirical evidence on the relationship between self-confidence and performance using a novel data set from the field. Exploiting the specific dual nature of top-tier Biathlon competitions, we find evidence for a positive causal effect of self-confidence on performance. In particular, we find that performance of male biathlon athletes at the shooting range deteriorates as they take more time for shooting as well as preparing before the shooting. For female athletes, we estimate a similar causal relationship, yet less pronounced and only in particular situations.

Further analyses show that the estimated positive effect of self-confidence for male athletes is observed mainly at the beginning of races. We do find a similar but smaller positive effect of self-confidence on performance for women at the beginning of races, however, only for sprint competitions. Concerning the experience of athletes, we find that the effect for men is only observed for relatively unexperienced athletes. From this we tentatively conclude that experience might have a mitigating effect on the positive association between self-confidence and performance.

Our results cannot reject the central assumption put forward by Compte and Postlewaite (2004), namely that higher levels of self-confidence affect performance positively. However, we cannot find robust evidence for a general relationship of self-confidence on performance for female athletes. This suggests that there is a gender difference in the way self-confidence influences performance.

We contribute to the growing literature on the effects of behavioral aspects and personality traits on performance and labor market outcomes. In particular, we find that competitors in a multi-task environment perform better when they are more self-confident. This relationship turns out to be sensitive to gender and experience of the contestants. While we observe a very specific form of competition, we firmly believe that top-level sports contests provide an excellent environment to study these effects.

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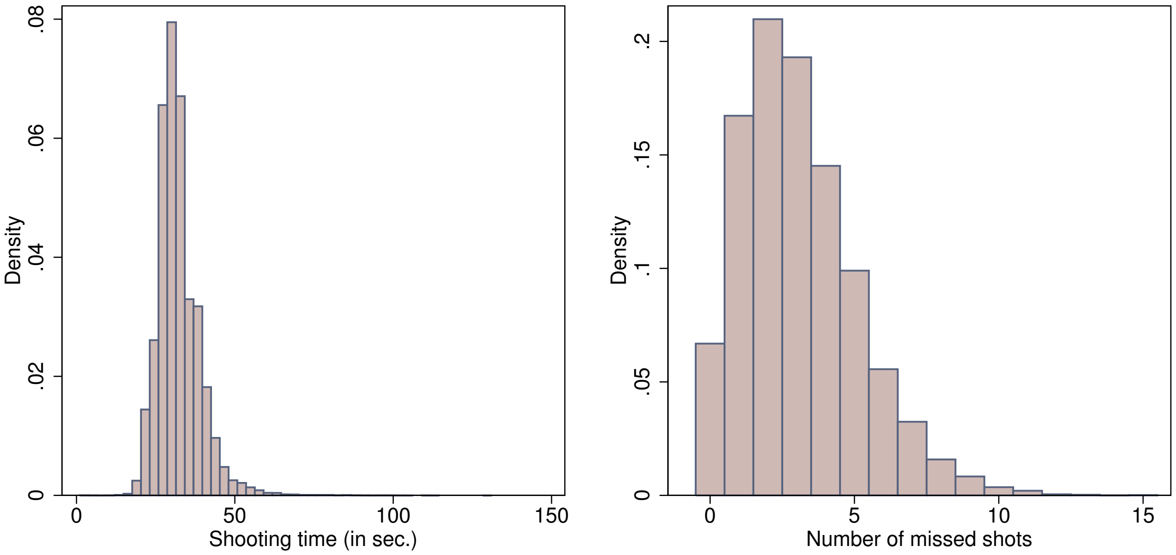
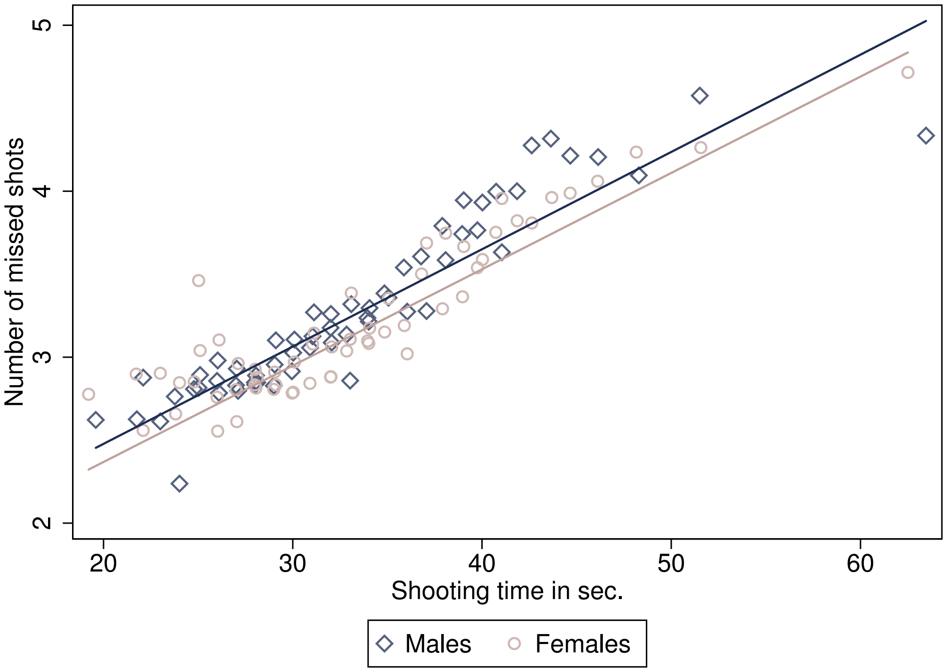
A. APPENDIX

Figure 1: Distribution of shooting time (measured in seconds) and number of missed shots.



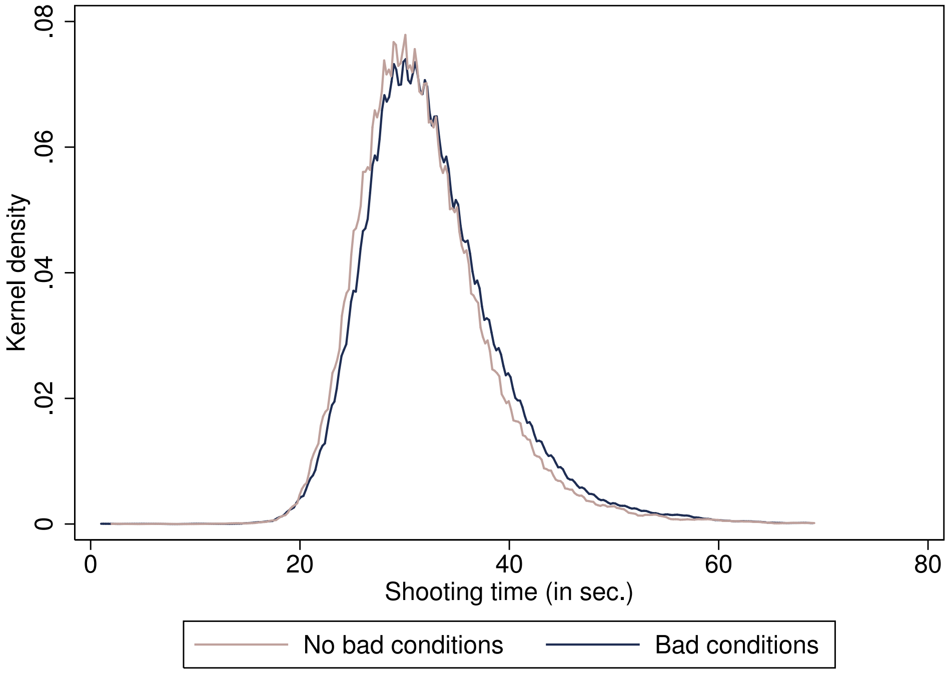
Notes: In this graph we plot the distribution of our self-confidence measure (shooting time in seconds) and our main outcome measure, the number of missed shots.

Figure 2: Number of missed shots against shooting time (in seconds).



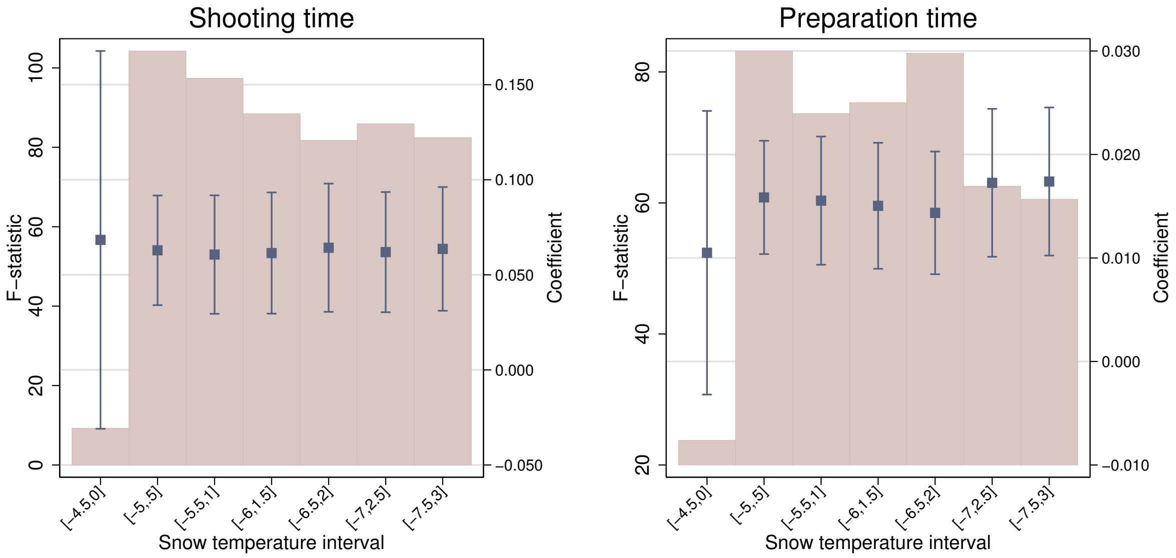
Notes: This graph provides the unadjusted relationship between our self-confidence measure (shooting time in seconds) and our main outcome measure, the number of missed shots. Observations are grouped into 50 equally sized bins per gender.

Figure 3: Kernel density of shooting time (in seconds) for different choices of the instrument.



Notes: This graph plots Kernel density estimates of the distribution of shooting time (in seconds) for both possible realizations of our instrumental variable. Bad conditions are defined as in equation (2).

Figure 4: First-stage coefficients for different choices of the snow temperature interval used to define the instrumental variable.



Notes: In this graph we provide different first-stage coefficients (right axis) and first-stage F-statistics for variations in the snow temperature interval in equation 2.

Table 1: Variable descriptions.

Variable	**Description**
Number of missed shots	Number of missed shots in shooting after loop l.
Shooting time (in sec.)	Time between the first and last shot fired at the shooting range.
Starting quartile	Quartile of the starting number in event e.
Lag after $l - 1$	Lag to preceding runner after previous loop $l - 1$ (in seconds)
Lead after $l - 1$	Lead to succeeding runner after previous loop $l - 1$ (in seconds)
World cup points to win	Possible world cup points to win if preceding runner is overtaken.
Foggy weather	= 1 if weather conditions are foggy.
Prone shooting	= 1 if shooting in loop l has to be taken prone.
Penultimate loop	= 1 if loop l is the penulimate loop (i.e., the last shooting loop)
Home event	= 1 if runner starts in an event which is in his country of citizenship.
Olympia or World Championship	= 1 if event is an olympic event or a world championship event.
Disciplines	
Individual	= 1 if event is individual.
Mass start	= 1 if event is mass start.
Pursuit	= 1 if event is pursuit.
Sprint	= 1 if event is sprint.

Table 2: Descriptive statistics.

	(1) All		(2) Men		(3) Women	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Number of missed shots	0.98	(0.98)	0.97	(0.98)	0.98	(0.99)
Shooting time (in sec.)	32.19	(6.74)	30.73	(6.48)	33.82	(6.64)
Starting quartile	2.48	(1.12)	2.48	(1.12)	2.48	(1.12)
Lag after $l - 1$	4.73	(9.75)	4.43	(9.64)	5.06	(9.85)
Lead after $l - 1$	4.73	(9.74)	4.42	(9.62)	5.07	(9.86)
World cup points to win	0.86	(1.24)	0.83	(1.23)	0.89	(1.25)
Wind speed (in km/h)	1.26	(0.97)	1.23	(0.96)	1.28	(0.98)
Foggy weather	0.02	(0.13)	0.02	(0.14)	0.02	(0.12)
Prone shooting	0.50	(0.50)	0.50	(0.50)	0.50	(0.50)
Penultimate loop	0.25	(0.43)	0.25	(0.43)	0.25	(0.43)
Home event	0.06	(0.24)	0.06	(0.24)	0.06	(0.23)
Olympia or World Championship	0.17	(0.38)	0.17	(0.38)	0.17	(0.38)
Discipline						
Individual	0.23	(0.42)	0.24	(0.42)	0.22	(0.41)
Mass start	0.09	(0.29)	0.09	(0.29)	0.09	(0.29)
Pursuit	0.29	(0.45)	0.28	(0.45)	0.29	(0.46)
Sprint	0.39	(0.49)	0.39	(0.49)	0.39	(0.49)
Runners	684		322		362	
Events	60		60		120	
N	73,171		38,523		34,648	

Notes: In this table we provide means and standard deviations of all variables used in our analyses, separately for men and women.

Table 3: Different snow conditions in the data.

Snow conditions	Freq.	Percent	Cum.
Packed	18,573	25.43	25.43
Granular	11,146	15.26	40.70
Packed powder	10,686	14.63	55.33
Hard packed	9,053	12.40	67.73
Hard packed variable	6,396	8.76	76.49
Wet	4,702	6.44	82.92
Powder	3,277	4.49	87.41
Compact	3,142	4.30	91.71
Hard	2,075	2.84	94.56
Wet & powder	1,906	2.61	97.17
Soft	1,465	2.01	99.17
Fine grained	605	0.83	100
Total	73,026	100	

Table 4: Main results for the effect of self-confidence on the number of missed shots.

	OLS			2SLS		
	(1) All	(2) Men	(3) Women	(4) All	(5) Men	(6) Women
Shooting time (in sec.)	0.0397***	0.0402***	0.0391***	0.0562***	0.0774***	0.0134
	(0.002)	(0.002)	(0.002)	(0.016)	(0.020)	(0.028)
Lag to preceding runner after previous loop (in sec.)	-0.0005	-0.0002	-0.0009	-0.0002	0.0006	-0.0011
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Lead to succeeding runner after previous loop (in sec.)	-0.0003	0.0009	-0.0018*	-0.0004	0.0006	-0.0020**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Possible WC points to win if preceding runner is overtaken	0.0205***	0.0236***	0.0174**	0.0182***	0.0170**	0.0200***
	(0.005)	(0.006)	(0.007)	(0.005)	(0.008)	(0.007)
Wind speed at time of start in m/s	0.0694***	0.0601***	0.0804***	0.0537***	0.0262	0.1060***
	(0.006)	(0.008)	(0.009)	(0.016)	(0.019)	(0.029)
Foggy weather	0.1902***	0.1989***	0.2044**	0.1529**	0.1203	0.2734***
	(0.047)	(0.056)	(0.085)	(0.060)	(0.078)	(0.103)
Prone shooting	-0.4534***	-0.4639***	-0.4425***	-0.5190***	-0.6161***	-0.3431***
	(0.020)	(0.027)	(0.029)	(0.068)	(0.089)	(0.113)
Penultimate loop	0.0203	0.0424**	-0.0031	0.0166	0.0435**	0.0100
	(0.014)	(0.017)	(0.022)	(0.015)	(0.018)	(0.025)
Discipline dummies *(reference category: individual)*						
Mass start	0.1453***	0.1643***	0.1216***	0.1743***	0.2284***	0.0757
	(0.018)	(0.023)	(0.028)	(0.034)	(0.043)	(0.057)
Pursuit	0.1206***	0.1183***	0.1194***	0.1366***	0.1560***	0.0956***
	(0.015)	(0.019)	(0.024)	(0.021)	(0.028)	(0.034)
Sprint	0.1396***	0.1701***	0.1011***	0.1374***	0.1502***	0.0927***
	(0.018)	(0.024)	(0.027)	(0.018)	(0.027)	(0.028)
Type of event dummies						
Home event	0.0256	0.0360	0.0135	0.0288	0.0379	0.0043
	(0.021)	(0.028)	(0.032)	(0.022)	(0.031)	(0.033)
Olympia or World Championship	-0.0293**	-0.0080	-0.0514***	-0.0163	0.0213	-0.0720**
	(0.012)	(0.016)	(0.017)	(0.018)	(0.023)	(0.029)
Starting number quartile dummies *(reference category: quartile 1)*						
Quartile 2	-0.0011	0.0129	-0.0165	-0.0002	0.0205	-0.0140
	(0.014)	(0.019)	(0.021)	(0.015)	(0.020)	(0.021)
Quartile 3	-0.0320*	-0.0363	-0.0266	-0.0283	-0.0277	-0.0324
	(0.017)	(0.024)	(0.023)	(0.017)	(0.026)	(0.023)
Quartile 4	-0.0479***	-0.0490**	-0.0451*	-0.0445**	-0.0451*	-0.0532*
	(0.018)	(0.025)	(0.027)	(0.019)	(0.026)	(0.029)
First-stage coefficient				0.7224***	0.8917***	0.5756***
				(0.082)	(0.125)	(0.106)
Kleinbergen-Paap rk F-statistic				77.7	51.1	29.3
N	35,913	18,797	17,116	35,913	18,797	17,116
R^2	0.2450	0.2426	0.2491	0.2373	0.2044	0.2299
Mean of outcome	1.04	1.03	1.05	1.04	1.03	1.05

Notes: This table presents our main results, the outcome variable in each column is the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression: Columns (1)–(3) are estimated via standard OLS where we ignore the endogeneity of shooting time, columns (4)–(6) are estimated via two-stage least squares. All models incorporate runner × year fixed effects. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Heterogeneous effects by age quartile.

	Men				Women			
	(1) Age Q1	(2) Age Q2	(3) Age Q3	(4) Age Q4	(5) Age Q1	(6) Age Q2	(7) Age Q3	(8) Age Q4
OLS estimates								
Shooting time	0.0433***	0.0392***	0.0362***	0.0418***	0.0343***	0.0429***	0.0440***	0.0362***
(in sec.)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
N	4,291	5,321	3,795	5,390	5,132	5,154	3,513	3,317
R^2	0.2860	0.2210	0.2177	0.2470	0.2632	0.2363	0.2504	0.2218
Mean of dep. var.	1.12	0.99	1.01	1.03	1.15	1.00	1.11	0.91
2SLS estimates								
Shooting time	0.0806**	0.1185***	0.0921	0.0425	-0.0871	0.0194	0.0864	0.0613
(in sec.)	(0.033)	(0.044)	(0.057)	(0.034)	(0.084)	(0.037)	(0.089)	(0.047)
N	4,291	5,321	3,795	5,390	5,132	5,154	3,513	3,317
R^2	0.2519	0.0319	0.1199	0.2470	-0.1416	0.2207	0.1988	0.2005
Mean of dep. var.	1.12	0.99	1.01	1.03	1.15	1.00	1.11	0.91
Kleinbergen-Paap rk F-statistic	24.0	8.8	6.5	20.4	5.6	14.9	3.1	5.3

Notes: This table presents heterogeneous results by age quartile, the outcome variable in each column is the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression on a different subsample. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Heterogeneous effects part I.

	Intermediate rank			
	Men		Women	
	(1) 1st half	(2) 2nd half	(3) 1st half	(4) 2nd half
OLS estimates				
Shooting time (in sec.)	0.0315***	0.0381***	0.0294***	0.0359***
	(0.002)	(0.003)	(0.003)	(0.003)
2SLS estimates				
Shooting time (in sec.)	0.0666**	0.0791***	0.0044	0.0263
	(0.032)	(0.027)	(0.039)	(0.037)
N	9,429	9,266	8,580	8,444
Mean of outcome	0.69	1.39	0.70	1.42
Kleinbergen-Paap rk F-statistic	26.1	28.3	9.8	21.3

	Missed shots in rounds before			
	Men		Women	
	(1) 1 or more	(2) None	(3) 1 or more	(4) None
OLS estimates				
Shooting time (in sec.)	0.0405***	0.0411***	0.0390***	0.0385***
	(0.002)	(0.004)	(0.003)	(0.003)
2SLS estimates				
Shooting time (in sec.)	0.0781**	0.0816***	0.0020	0.0372
	(0.030)	(0.026)	(0.039)	(0.048)
N	13,129	5,511	11,890	5,112
Mean of outcome	1.07	0.94	1.11	0.92
Kleinbergen-Paap rk F-statistic	25.3	36.2	13.0	15.7

	Unimportant events			
	Men		Women	
	(1) Unimportant	(2) Others	(3) Unimportant	(4) Others
OLS estimates				
Shooting time (in sec.)	0.0424***	0.0334***	0.0385***	0.0429***
	(0.002)	(0.005)	(0.002)	(0.004)
2SLS estimates				
Shooting time (in sec.)	0.0574***	0.0872**	0.0022	0.1783
	(0.016)	(0.040)	(0.024)	(0.136)
N	15,372	3,334	13,568	3,462
Mean of outcome	1.03	1.05	1.04	1.09
Kleinbergen-Paap rk F-statistic	67.2	43.3	22.4	2.5

Notes: This table presents heterogeneous results by intermediate rank, missed shots in the loops before and by the importance of the tournament. The outcome variable in each column is the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression on a different subsample. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Loop progression.

	Men			Women		
	(1) Loop 2	(2) Loop 3	(3) Loop 4	(4) Loop 2	(5) Loop 3	(6) Loop 4
OLS estimates						
Shooting time (in sec.)	0.0424***	0.0381***	0.0323***	0.0382***	0.0409***	0.0360***
	(0.003)	(0.004)	(0.004)	(0.003)	(0.005)	(0.003)
2SLS estimates						
Shooting time (in sec.)	0.0811***	0.0731	0.0424	0.0447**	0.1944	-2.8573
	(0.017)	(0.145)	(0.082)	(0.022)	(0.322)	(20.947)
N	9,561	4,370	4,368	8,649	4,050	4,049
Mean of outcome	1.08	0.90	1.04	1.08	0.95	1.07
Kleinbergen-Paap rk F-statistic	68.0	1.7	4.3	88.9	0.6	0.0

Notes: This table presents separate results for every loop in a Biathlon race. The outcome variable in each column is the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression on a different subsample. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Heterogeneous effects by specialist type.

	Men			Women		
	(1) Generalists	(2) Shooters	(3) Runners	(4) Generalists	(5) Shooters	(6) Runners
OLS estimates						
Shooting time (in sec.)	0.0441***	0.0390***	0.0388***	0.0401***	0.0382***	0.0394***
	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)
2SLS estimates						
Shooting time (in sec.)	0.0796*	0.0820**	0.0715**	0.0515	0.0308	-0.0137
	(0.045)	(0.034)	(0.030)	(0.105)	(0.037)	(0.046)
N	4,641	6,466	7,690	4,669	5,901	6,546
Mean of outcome	1.06	1.00	1.04	1.03	1.02	1.09
Kleinbergen-Paap rk F-statistic	11.5	15.1	24.6	3.0	19.6	10.2

Notes: This table presents heterogeneous results by specialist type (classified as described in sectionV.2). The outcome variable in each column is the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression on a different subsample. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: *Robustness check* — Preparation time as an alternative measure of confidence.

	OLS			2SLS		
	(1) All	(2) Men	(3) Women	(4) All	(5) Men	(6) Women
Preparation time (in sec.)	0.0189***	0.0197***	0.0183***	0.0132***	0.0140***	0.0041
	(0.000)	(0.000)	(0.000)	(0.003)	(0.003)	(0.008)
First-stage coefficient				3.0681***	4.9301***	1.8678***
				(0.357)	(0.469)	(0.537)
Kleinbergen-Paap rk F-statistic				73.9	110.4	12.1
N	35,913	18,797	17,116	35,913	18,797	17,116
R^2	0.4487	0.4499	0.4496	0.4261	0.4290	0.3027
Mean of outcome	1.04	1.03	1.05	1.04	1.03	1.05

Notes: In this table we use preparation time as an alternative measure of self-confidence to re-estimate equation 1. The outcome variable in each column is still the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression: Columns (1)–(3) are estimated via standard OLS where we ignore the endogeneity of shooting time, columns (4)–(6) are estimated via two-stage least squares. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 10: Differential results by discipline.

	(1) Individual	(2) Mass start	(3) Pursuit	(4) Sprint
Men				
Shooting time (in sec.)	0.1040***	0.1381	0.0956	0.0691***
	(0.032)	(0.257)	(1.011)	(0.016)
N	5433	1950	6433	4859
R^2	0.2374	-0.0329	0.1695	0.3462
Mean of outcome	0.98	0.84	0.94	1.30
Kleinbergen-Paap *rk* F-statistic	24.9	1.1	0.0	89.5
Women				
Shooting time (in sec.)	0.2326	-0.0468	-0.1703	0.0707***
	(0.380)	(0.145)	(0.221)	(0.022)
N	4593	1955	6129	4357
R^2	-0.5729	0.0588	-0.9294	0.3176
Mean of outcome	1.02	0.88	0.99	1.25
Kleinbergen-Paap *rk* F-statistic	0.4	1.7	1.2	64.0

Notes: In this table we present differential results for all Biathlon disciplines. We only report 2SLS estimates. The outcome variable in each column is still the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression on a different subsample. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 11: The effect of shooting time on missed shots where sample does not contain the last shooting of every event

	Men		Women	
	Individual (1)	Sprint (2)	Individual (3)	Sprint (4)
Shooting time (in sec.)	0.1356***	0.0896***	0.2407	0.0527*
	(0.046)	(0.021)	(0.251)	(0.032)
N	3622	4859	3062	4355
Mean of outcome	0.9191	0.9127	1.0179	0.8834
Kleinbergen-Paap *rk F*-statistic	14.97	79.64	1.11	37.69

Notes: In this table we omit the last shooting from every event and re-estimate Table 4. We only report 2SLS estimates. The outcome variable in each column is still the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression on a different subsample. All models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 12: *Robustness check* — Snow temperature as an alternative IV

	OLS			2SLS		
	(1) All	(2) Men	(3) Women	(4) All	(5) Men	(6) Women
Shooting time (in sec.)	0.0397***	0.0402***	0.0391***	0.0353***	0.0443***	0.0116
	(0.002)	(0.002)	(0.002)	(0.010)	(0.009)	(0.033)
First-stage coefficient				-0.1536***	-0.2370***	-0.0685***
				(0.012)	(0.016)	(0.014)
Kleinbergen-Paap *rk F*-statistic				167.1	209.0	24.1
N	35913	18797	17116	35913	18797	17116
R^2	0.2450	0.2426	0.2491	0.2444	0.2422	0.2272
Mean of outcome	1.04	1.03	1.05	1.04	1.03	1.05

Notes: In this table re-estimate Table 4 with a different instrumental variables (snow temperature in continuous form). The outcome variable in each column is the number of missed shots. The unit of observation is a single loop. Each column represents a separate regression, and all models incorporate runner × year fixed effects and the same set of covariates as in Table 4. Standard errors in given in parentheses are cluster on the runner-level, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.