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Working Papers in Economics and Statistics

2017-24

University of Innsbruck
http://uibk.ac.at/eeecon/

University of Innsbruck
Working Papers in Economics and Statistics

The series is jointly edited and published by

- Department of Banking and Finance
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- Department of Statistics

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Choking under pressure of top performers: Evidence from Biathlon competitions*

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November 30, 2017

Abstract

Psychological pressure affects performance. This is especially true for individuals completing precision tasks in decisive situations, such as assessment tests, job talks, or sports competitions. In this paper, I shed light on detrimental effects of pressure on performance, a phenomenon known as “choking under pressure”. I analyze a unique setting in which the effect of pressure on performance is naturally observable: Biathlon World Cup competitions. As the last shot in the final bout of shootings is regularly decisive for the victory, pressure is highest on the leader of the competition not to miss this last shot. Using event data from 11 seasons of Biathlon World Cup, I find strong evidence for “choking under pressure”, implying that especially leaders are more likely to fail decisive shots. Furthermore, taking more time for the last shootings bout leads to a decrease in performance. Finally, I show suggestive evidence for a momentum effect – after missing a shot during the last shooting bout, the probability of missing the last shot decreases.

JEL: L83, M51, M54, Z20, L83.

Keywords: Choking under pressure; psychological pressure; Biathlon.

*I thank Caroline Bonn, Jürgen Huber, Michael Kirchler, Stefan Palan, and Matthias Sutter for very valuable and helpful comments. I am grateful to Desislava Dimitrova and Philipp Steinbach for excellent research assistance. Financial support from the Austrian Science Fund FWF (START-grant Y617-G11 and SFB F63) is gratefully acknowledged.

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1 Introduction

Psychologists define the phenomenon of sub-optimal performance despite a high level of motivation as "choking under pressure" (e.g., Baumeister, 1984). Dan O'Brien, a former decathlon Olympic champion and three-times world champion became "famous" for choking under pressure, as he missed his three pole vault attempts at the U.S. trials for the 1992 Summer Olympics as the current world champion. Three weeks later he achieved a new world record.[1] Performing worse than usual is documented in many other high-performance sports contests (Beilock and Gray, 2012), like soccer (Dohmen, 2008), basketball (Cao et al., 2011), or golf (Hickman and Metz, 2015).

Similarly, there are plenty of situations in which pressure, together with high monetary stakes, arises in economic decision making, such as trading decisions in financial markets, individuals trying to buy a product within limited time, job talks, or assessment environments. People participating in negotiations have to decide quickly how to handle different situations and whether or not to accept an offer. At the workplace, competitions for promotions or the threat of punishment are among the most common pressure factors. Such dynamic competitive settings can cause mixed performance effects, i.e., despite high motivation and determination to perform well, individuals' performance might be harmed. Investigating how people perform under pressure is thus crucial for many aspects in business and economics, especially in those high monetary stakes environments.

Measuring the effect of pressure is difficult. Even if the dimensions of the output deficit due to choking would be observable, it is often hard to ascribe a performance deterioration unambiguously to choking under pressure. Naturally occurring situations, such as the ones discussed in the preceding paragraph, are often too complex to be analyzed. An alternative is to use data from professional sports contests. These activities are particularly appropriate for analyzing the impact of pressure on performance because they often involve explicit randomization (see, e.g., Dohmen, 2008; Apesteguia and Palacios-Huerta, 2010; Cao et al., 2011; Kocher et al., 2012; Feri et al., 2013; Cohen-Zada et al., 2017). Furthermore, failure and success in professional sports tasks are easy to measure (e.g., scoring a goal or not). The one-dimensionality of the tasks (e.g., kicking a ball) is another advantage. Moreover, these sports contests can be described as authentic working conditions with high stake incentives.

One theory suggests that athletes choke under pressure because high levels of pressure can distract the individual from performing her task (Wine, 1971). Other theories focus on the fact that pressure raises self-consciousness and anxiety about performing correctly. Attention-to-skill processes are thought to disrupt well-learned or internalized procedures (Kimble and Perlmuter, 1970; Langer and Imber, 1979; Masters, 1992; Lewis and Linder, 1997). Choking is not just poor performance; it is performing more poorly than expected in situations where performance

[1] http://www.smithsonianmag.com/science-nature/the-science-of-choking-under-pressure-133896043/?no-ist.

pressure is at a maximum given one's skill level (Beilock and Gray, 2012). Whether it is a high school student taking the Scholastic Assessment Test (SAT), a golf player trying to reach the cut for the Professional Golfers' Association (PGA) TOUR, or a violinist auditioning for an orchestra. People frequently find themselves in high stakes situations where performing their best carries implications for future opportunities and success. In these situations the desire and motivation to perform well causes pressure.

The goal of this paper is to shed light on and extend the understanding of performance under pressure using individual sports data in a highly competitive environment with two different tasks. More specifically, are top athletes choking under pressure in a sport with the novel combination of an exhausting physical and a precision task, and what drives it? For this purpose, I use data from professional Biathlon contests, i.e., World Cup events over 11 seasons (2005/06 – 2015/16) for two competition types – pursuit and mass start.[2] Biathlon is a winter sport in which athletes compete by alternating skiing and shooting with five shots per bout. The combination of cross-country skiing (exhausting physical task) and rifle shooting (precision task) implies that athletes are left with time to think about their performance during skiing, which makes the sport extremely mentally demanding. For this reason, Biathlon data serve as an excellent database for examining performance under pressure.

An important notion of the analysis is to hypothesize that pressure is mainly related to two aspects: (a) the round within a competition, with the final round being the one with the highest pressure, and (b) the positioning of athletes towards the end of the competition, with the top athletes feeling the most pressure, especially in the precision (shooting) task. This logic is applied as a result of a number of real-life examples in which a variety of athletes perform sub-optimally in situations which amplify the importance of doing well (see, e.g., Lewis and Linder, 1997; Cao et al., 2011; Ariely et al., 2009; González-Díaz et al., 2012; Hickman and Metz, 2015). A prominent illustrative example in professional tennis was the 1993 Wimbledon final Jana Novotná versus Steffi Graf. Novotná led Graf 6–7 6–1 4–1 and at 40–30 in the sixth game of the deciding set had a service point for a 5–1 lead over the German. But Novotná double-faulted, arguable beginning the greatest disintegration in a Wimbledon final. Not much more than ten minutes later Graf had won 7–6 1–6 6–4.[3] To hypothesize that the last shot of the last bout of shootings in Biathlon is the one in which the athletes experience most pressure is additionally supported by several blog entries and sports journalists.[4] Therefore, I hypothesize that the last shot of the last bout of shootings is the one in which athletes experience most pressure. Choking

[2]The reason for focusing on these two competition types is that here athletes compete face-to-face for the victory towards the end of each race. In the other two competition types (individual and sprint) athletes start in intervals and don't know their final rank until the very last competitor finishes. For details on the rules and competition types see Section 3.

[3]https://www.theguardian.com/observer/osm/story/0,,641727,00.html.

[4]For example, see https://www.nytimes.com/2014/02/17/sports/olympics/biathlon-penalty-loop-is-like-the-dunce-cap-of-the-olympics.html and https://www.reuters.com/article/olympics-biathlon-shipulin/olympics-biathlon-oh-shoot-last-shot-miss-ends-shipulins-dream-idUSL5N0LD0LR20140208.

under pressure is defined as missing the fifth shot from the last bout of shootings. Furthermore, I hypothesize that longer shooting times are an indication of thinking about performance. This conjecture is based on the following observations: professional Biathlon athletes train up to a point where shooting becomes an automated motor skill and is best performed when the athlete does not think but rather just "gets the job done" (Leavitt, 1979; Baumeister, 1984; Smith and Chamberlin, 1992; Lewis and Linder, 1997; Beilock and Carr, 2001; Beilock et al., 2002). Longer shooting time could therefore be an indication that the athlete is actively reflecting on her performance. This could lead to a higher level of psychological pressure and to a higher probability of missing the decisive shot.

I find that being higher up in the ranking right before the last shooting leads to a higher probability of missing the last shot, providing evidence for a negative effect of pressure on performance. Moreover, I show that longer shooting times of the last shootings bout increase the probability of missing the final shot, suggesting that longer shooting times foster reflecting on performance and potentially result in higher stress levels. In addition, I report that larger time differences to the leader at the beginning of the last shooting bout are related to lower shooting accuracy of the followers which is an indication of an attempt to decrease the shooting time by taking more risks to climb up the ranking.

The remainder of the paper is structured as follows: Section 2 provides a brief overview of the existing literature on performance under pressure, Section 3 provides a short description of Biathlon and its rules, Section 4 describes the data and variables, Section 5 presents the results, and Section 6 concludes.

2 Related Literature

The idea that psychological factors, such as pressure, are relevant for human decision making goes back to Hume (1739). The topic of performance under pressure has since received much attention in both, economics and psychology. Hill et al. (2010) discuss the so-called (inverted) U-shape theory about performance under pressure, which was initially proposed by Yerkes and Dodson (1908). The theory states that an increase in pressure causes performance to increase up to a point at which performance starts declining. Hardy and Parfitt (1991) argue that when the top point of the U-shaped curve is reached, performance drops drastically, resulting in an asymmetric U-curve. Psychological studies refer to such extreme situations as choking under pressure (see, among others, Baumeister, 1984; Baumeister and Showers, 1986; Beilock and Carr, 2001, 2005).

Many research papers use real-life data and laboratory experiments (see, e.g., Baumeister, 1984; Baumeister et al., 1985; Heaton and Sigall, 1991; Dohmen, 2008; Apesteguia and Palacios-Huerta, 2010; Cao et al., 2011; Beilock and Gray, 2012) do show that pressure to perform well often causes people to perform below their actual abilities. In contrast, Kocher et al. (2012) and

Feri et al. (2013) show that pressure does not cause people to underperform. In most of the afore mentioned papers, sports data is employed to analyze choking. Studies focusing on both team and individual sports data analyze the impact of pressure on performance in light of other variables as well, such as score difference, audience characteristics, skill levels, anxiety, self-focus, self-confidence, whether the contestant/team is winning or losing, and positive momentum (e.g., Wright et al., 1991, 1995; Masters et al., 1993; Lewis and Linder, 1997; Butler and Baumeister, 1998; Dandy et al., 2001; Wallace et al., 2005; Jordet et al., 2007; Dohmen, 2008; Cao et al., 2011; Hickman and Metz, 2015; Cohen-Zada et al., 2017; Harb-Wu and Krumer, 2017).

In a randomized natural experiment, Apesteguia and Palacios-Huerta (2010) collect data on 129 penalty shoot-outs from ten different national and international soccer competitions (World Cup, Continental Cups, National Cups) to examine the importance of psychological pressure in sequential tournaments. Penalty shoot-outs are used to determine the winner of a tied game. Such shoot-outs fulfill the criterion of a randomized natural experiment, as the order of the penalty kicks is determined by the toss of a coin, where the team who wins the toss has to kick first. Results suggest that being a first-mover significantly increases the probability of winning. In particular, their data shows that, despite an initial winning probability of 50% for both teams, the first-kicking team won in 60.5% of the cases. Apesteguia and Palacios-Huerta (2010, p. 2563) interpret these results as "support for a source of psychological pressure that has a detrimental effect on performance, and that is different from others such as high stakes, social pressure or peer pressure previously documented in the literature." Kocher et al. (2012) extended the data set to 540 penalty shootouts. This super-set allows the authors to address the alleged first-mover advantage in a more comprehensive way and the authors find that first-kicking teams win in 288 cases (53.3%, not significantly different from 50%, however).

Feri et al. (2013) construct basketball free-throw competitions in which professional basketball players take part. Participants are matched in pairs and perceive pressure which is common in basketball games. The authors do not find any first-mover advantage. The analysis of their data actually shows that second movers, when under psychological pressure, perform better. Kolev et al. (2015) use penalty shoot-out data from the National Hockey League (NHL). They find first-mover advantage when the first-"kicking" team scores first and, inversely, second-mover advantage when the first-"kicking" team fails to score first. Baumeister and Steinhilber (1984) show that home teams in the Baseball World Series tend to win games early in the series but to lose decisive seventh games. Paserman (2010) exhibits that professional tennis players' performance worsens on important points and shows that, facing an opponent of equal skills, the player who is able to cope better with this detrimental performance, increases her chance of winning from 50% to 75-80%.

Cao et al. (2011) use National Basketball Association (NBA) free-throw data from 2002/03 until 2009/10. They show that players on average shoot 5-10 percentage points worse in the final seconds of very close games than usual. They conclude that performance deterioration is magnified if players have a generally lower skill level of free-throw shooting or on the second shot of a pair of shots after missing the first one. In contrast, Dohmen (2008) uses penalty kick data from the German Premier Football League and finds no such interdependencies. The reason for these contradicting results could be traced back to different game structures of soccer and basketball.

Several papers show that people are more prone to choking when they must cope with supportive (home) audiences (Baumeister and Steinhilber, 1984; Butler and Baumeister, 1998; Wright et al., 1991, 1995; Wallace et al., 2005). In general, supportive audiences can help performers to seize their highest potential. For example, the so-called home advantage, when athletes perform better when they are at home, is mainly explained by the fact that supportive audiences encourage better performances than unsupportive audiences. However, using penalty kick data from the German Premier Football League, Dohmen (2008) finds that being the home team is associated with a lower score. In the same spirit, Harb-Wu and Krumer (2017) use Biathlon data of individual competitions and find a negative effect in terms of lower shooting accuracy of high performance athletes when competing in home countries. By manipulating audience support in laboratory experiments, Butler and Baumeister (1998) further found that participants performed worse when performing for supportive versus unsupportive audiences. As soon as athletes care about the happiness of the audience, these results can be explained by top athletes feeling greater pressure to avoid failure (Heaton and Sigall, 1991). Failing is bad enough in itself for competitors with an unsupportive audience, but in the case of supportive audiences, athletes have to deal with the burden of disappointing others. Another potential explanation is that supportive audiences usually have high expectations of the home athletes' performance, which further increases the pressure on performance (Baumeister et al., 1985, 1990).

Hickman and Metz (2015) study the choking phenomenon by investigating the explicit link between rewards and performance using PGA TOUR data from 2004 until 2012. As opposed to tournament theory (e.g., Lazear and Rosen, 1981; Rosen, 1986; Lazear, 2000), which suggests that very large rewards elicit high effort and thus increase performance, they conclude that high monetary prizes associated with pressure lead to deterioration in performance of professional golf players. Related to this, Pope and Schweitzer (2011) analyze over 2.5 million golf putts of the PGA TOUR using precise laser measurements and show evidence for loss aversion even among the top ranked golfer players.

Researchers have proposed that pressure to perform at a high level prompts attention to the step-by-step components of a well-learned skill or tasks normally performed automatically such as shooting in Biathlon or putting in golf (Baumeister, 1984; Lewis and Linder, 1997; Beilock and Carr, 2001; Beilock et al., 2002; Harb-Wu and Krumer, 2017). By conducting laboratory experiments, Baumeister (1984) argues that competition induces arousal which results in attentional focus on oneself and disruption of well-learned skills. Well-learned skills do not require constant attentional control during execution (Leavitt, 1979; Smith and Chamberlin, 1992). Attending to a step-by-step execution of a proceduralized skill may actually disrupt execution (Kimble and Perlmuter, 1970; Langer and Imber, 1979; Baumeister, 1984; Lewis and Linder, 1997; Beilock and Carr, 2001). In particular, "reinvesting" attention in a task previously performed automatically leads to higher levels of anxiety and self-focus and, thus, to performance deterioration (Otten, 2009). Masters et al. (1993, p. 655) defined the act of reinvestment as "purposefully endeavoring to run a skill with explicitly available knowledge of it," by "reinvesting" actions and precepts with attention. The authors use a 20-item reinvestment scale and distribute it to a sample of novice golf putters, professional squash and tennis players. They find that a lower score on the scale is associated with better performance under pressure. This finding is supported by Jackson et al. (2006) using field hockey and soccer player data.

Moreover, underperformance in high-pressure situations could derive from the performers being distracted from performing their tasks. Due to pressure, individuals' attention can be diverted away to task-irrelevant thoughts, such as worries about the situation and its consequences (Baumeister, 1984; Beilock and Carr, 2001; Lewis and Linder, 1997). In other words, pressure creates a dual-task environment in which situation-related worries compete with the attention needed to execute the task at hand. For example, Beilock et al. (2004) find that math problems heavily dependent on working memory (i.e., requiring the online maintenance and manipulation of intermediate problem sets) are solved less accurately in a high-pressure test compared with a low-pressure test. In contrast, math problems that are well practiced are performed equally well in low- and high-pressure situations.

Another potential moderator of choking under pressure can be psychological momentum (Iso-Ahola and Dotson, 2014). Prior success can produce an increased sense of confidence and efficacy, giving rise to perceptions of momentum. Cohen-Zada et al. (2017) examine the causal effects of psychological momentum on performance in Judo. Their results show that having a psychological momentum advantage significantly increases the probability of winning among male but not among female athletes. They further relate these results to previously established theories about testosterone levels in men and women. In general, testosterone increases after a victory and decreases after a loss. Those effects are stronger among men than women (Booth et al., 1989; Elias, 1981). Salvador et al. (2003) support these results by showing that Judo contestants with higher pre-contest testosterone levels obtained better results in future matches. In essence, momentum and testosterone levels can motivate performers to persevere to achieve success in high-pressure situations.

Critical abilities, such as a professional player's expertise in her own sport, experience or confidence, can be thought of as pressure moderators as well. Baumeister (1984, p. 610) defined pressure as "any factor or combination of factors that increases the importance of performing well," and choking as any performance decrements. González-Díaz et al. (2012) use tennis point-level data from twelve years of the US Open tournament to assess how contestants adapt their behavior to the importance of a specific situation and show that individual skills and psychology matter. They establish that critical abilities, defined as the ability to adjust one's performance to the importance of a situation, without necessarily improving one's average performance differ significantly across professional tennis players. In particular, they show that some players are capable of playing their best games in the most important situations, in which the level of pressure is highest, while others exhibit a decrease in performance in such situations. In fact, it seems that some athletes not only tend not to choke, but actually tend to perform better than usual under pressure.

3 Biathlon

Biathlon is a winter sport combining cross-country skiing and rifle shooting. Alternating skiing and shooting, athletes compete under the pressure of the clock that continues to run as they stop to shoot. The athletes ski distances varying from 7.5 (6) to 20 (15) km for male (female) competitors, interrupted two or four times by stops at the shooting range, with both the skiing distance and the number of shooting bouts depending on the type of competition. The athletes shoot from two positions – prone and standing – in various different sequences depending on the competition. Whatever the shooting position is, the athlete must keep both skis on and cannot use any support. The main difficulty for the athlete is to slow her heart rate down so that she can target accurately.

In each shooting stage the athlete has five shots to hit five targets at a distance of 50 m. The diameter of the target hit area is 4.5 cm for prone and 11.5 cm for standing. If an athlete hits the black target it turns white to signal that the shot hit the target. There is a penalty for each missed shot, so athletes must balance speed on the course and on the range with shooting accuracy. Penalties for missed shots are imposed as either one minute added time per missed target for the individual competition or as a 150 m penalty loop per missed shot for all other competition types (see Table 1 for more details on the competition types).

In general, the athlete starts at the starting line, skis one loop, stops at the shooting range to shoot, skis another loop, stops again at the shooting range to shoot, and so on, until the athlete has completed all bouts of shootings and skis another (final) loop. The athletes are responsible for their own actions, such as choosing a shooting lane, counting the number of missed shots, and skiing the correct number of penalty loops.[5]

Biathlon is not governed by the Fédération Internationale de Ski (FIS). Instead, since 1993, the International Biathlon Union (IBU) has been the international governing body of Biathlon. It encompasses 66 member nations and has its headquarters in Salzburg, Austria. IBU has authorized eight international biathlon disciplines: individual, sprint, pursuit, mass start, relay, mixed relay single-mixed relay, and super sprint. Of these eight, five are part of the Winter Olympic Games: individual, sprint, pursuit, mass start and relay. Table 1 provides a summary

[5]Athletes are assigned at the first shooting bout in mass start by their starting number.

analysis of the five Olympic competitions.

Table 1: Competitions' summary: type, distance, number of shootings, penalty

Competition type	Distance male (female)	Shooting bouts	Penalty per missed target
Individual	20 (15) km	4	1 minute
Sprint	10 (7.5) km	2	1 extra loop (150 m)
Pursuit	12.5 (10) km	4	1 extra loop (150 m)
Mass start	15 (12.5) km	4	1 extra loop (150 m)
Relay	7.5 (6) km	2	1 extra loop (150 m)

Note that each relay involves four athletes. Each of them has to ski the mentioned distance and shoot once in prone and once in standing position. Eight instead of five bullets are available for every shooting bout per athlete, but the last three can only single-loaded manually. Only if an athlete is not able to hit the five targets with eight shots, a penalty loop is to ski.

The qualifier for the pursuit competition can be the individual or the sprint. The starting times in the pursuit are based on time difference to the winner of the qualifying competition, i.e., the winner of the qualifying competition starts first and the other athletes follow this winner with time delay. The starting field is limited to 60 athletes who normally start within less than five minutes. The competition consists of five skiing loops and four bouts of shooting. Athletes must take their firing positions (lane) in the order in which they enter the range – meaning that the leader takes the first free lane (on the far right of the range), the second athlete takes the second free lane and so on. The sequence of shooting bouts is prone, prone, standing, standing. For each missed target out of the five shots per bout, the athlete must ski the 150 m penalty loop. These features indicate that competitors know their position at any time, including the psychological thrill of athletes pursuing others ahead of them.

The mass start offers ultimate suspense for spectators and athletes due to the simultaneous start by all of the competitors. The format of the mass start is similar to the pursuit except that the course is a little longer and all athletes start at the same time. The field is limited to the top 30 athletes based on their world ranking. In the analysis, I will focus on the pursuit and the mass start competition types because these formats are the only ones in which the first one entering the finish line is always the winner of the race.

4 Data and Variables

4.1 Collection and Content of Data

The data was collected for the World Cup pursuit and mass start competitions from the seasons 2005/06 until 2015/16. The reason for choosing World Cup competitions is that these events are the largest international Biathlon competitions. World Championships and Olympic Games are excluded because the incentives in these types of competitions are regarded as different;

incentives are even more convex and in general higher at big events because of intensive media focus on the medal winners.

As mentioned earlier, the reason for choosing pursuit and mass start competition types is the similarity in format and the head-to-head character. Each competition data set contains information about the season in which the competition was held, the venue of the competition, gender of the athletes, weather conditions, names, nationality and starting number of the athletes, shooting and loop times, the rank after each loop, and detailed information about missed (not missed) targets for every single shot at each shooting bout.[6] The data for each competitor is split per round.

For the purposes of this study, and for reasons of comparability and consistency among the two competition types, I restrict the analysis to the top ten athletes at the beginning of the last shooting bout of each competition. The reason is that this sample is most representative to investigate performance under pressure, as increasing pressure is related to the ones highest in the rankings towards the final phase of a competition.[7]

In total, 135 World Cup competitions through the past 11 seasons were analyzed – 85 pursuit competitions and 50 mass starts.[8] The data is split per round for the top ten athletes at the final shooting bout for each competition. Only the last bout is of major interest in the analysis. This leads to a total of 1350 last shooting bout observations.

4.2 Variables

Next, I examine the model which I employ to investigate athletes' performance under pressure. The goal is to isolate the impact of pressure by only using data from the fourth round of the competitions where the level of excitement, stress and pressure is the highest. Furthermore, the fifth and final shot from the fourth bout of shootings is the one at which pressure peaks for those about to finish in the top positions. Thus, I concentrate on this particular moment in the competition. I define missing the decisive fifth shot as choking under pressure and analyze the factors that increase/decrease the probability of missing the fifth shot. I run probit regression models in which the dependent variable is whether or not the fifth shot was missed, i.e., a binary variable equal to 1 if the shot was unsuccessful and 0 if the shot was successful ($missed5$). By including independent variables, I exemplify different ways in which the level of pressure can be influenced. The independent variables are the following:

Shooting lane number at the fourth bout of shootings (*lane*): This variable serves as a proxy for relative performance, i.e., the rank at the beginning of the final shooting bout. As previously discussed, athletes must take their firing positions in the order in which they enter

[6] The data set has been compiled by a research assistant based on the official information on the IBU website.

[7] The main reason to restrict the analysis to the top ten athletes is that in most competitions they are competing for the victory – the time difference before the last shooting bout is usually within one penalty loop.

[8] This is not a complete set of all competitions which took place because not all information was available during the data collection phase.

the shooting range, starting with the first available lane on the far right, i.e., the athlete who arrives first takes shooting lane number one, the second athlete takes shooting lane number two and so on.[9] Thus, the fastest competitors and those with the highest probability to finish in the top positions occupy shooting lanes with lower numbers. I expect those who are fastest to experience the highest level of pressure to maintain their rankings during the final shooting phase of the competitions if the time difference between the athletes is not too large. It might also be that athletes close behind the leader face severe pressure to catch up the leader.

Missed fourth shot in the fourth round of shootings ($missed4$): Using this variable I can study whether a momentum effect exists, i.e., whether missing the fourth shot leads to higher pressure and a higher probability of missing the fifth shot.

Missed shots in the fourth round of shootings ($missedbefore5$): This variable allows an alternative investigation of a possible momentum effect, measured by the number of missed shots before the final shot (sum of missed shots $1 - 4$ in the final shooting bout).

Total shooting time of the fourth shooting bout (*shtime*): This variable aims to check whether there is a relationship between the speed and the success of shootings. As argued before, I expect that the likelihood of success, i.e., not missing the fifth shot, decreases with longer shooting time.

Ability (*ability*): This variable serves as a proxy for the capacity of each athlete. The measure is created by reconstructing every athlete's position in the pursuit and mass start World Cup standings. We use the world ranking of each athlete in the respective discipline before the start of each competition. The purpose of this variable is to check whether athletes with greater ability are also better at shooting and coping with pressure.

Time difference to the athletes ahead ($diffatime$): I further construct a variable for the time difference between an athlete and the athlete ahead of her, measured in seconds. The time difference is calculated at the time when competitors arrive at the shooting range in the fourth round. Smaller time differences at the beginning of the round of shootings could be associated to higher pressure not to miss a shot.

Time difference to the leader (*atime*): Another possible explanatory variable could be the time difference in seconds to the leader. This indicates the time an athlete has to catch up to win the competition.

Furthermore, I include controls for gender (*male*), the wind speed (*wind*), and a dummy variable for the competition type. The data for *wind* is downloaded from the official IBU website and measures the wind direction and speed 30 minutes after the start of each of the competitions. As the athletes in our data complete the pursuit and mass start competitions on average in 28 and 32 minutes respectively, the measure for *wind* is a close proxy for the actual wind speed at the moment in which an athlete is performing the final fifth shot.

[9] In some cases it could be the case that the fastest ten athletes are not allocated to the first ten lanes due to slower athletes which are one round behind.

5 Results

Table 2 shows the summary statistics of the shooting data in percent of all shots (missed and not missed) for all competitions (top part), pursuit (middle part), and mass start (bottom part). The table presents the missed shots in percent per bout of each shooting. For instance, I observe 822 misses out of 6,750 shots in total (12.2%) and 14.9% of the fifth shoot are missed in the fourth bout of shootings. Obviously, the majority of missed shots are during the third and fourth bouts of shootings which is due to the standing position (the first two bouts are in prone position). It is understood that the standing position is less stable compared to the prone position and thus results in less accuracy even when the target is larger (Hoffman et al., 1992; Groslambert et al., 1998). Moreover, in both types of competitions athletes tend to miss the fifth shot of the third and fourth bouts of shootings most often. Interestingly, during the prone (standing) shooting bouts the accuracy of shots increases (decreases) during the task. Another illustration of these statistics is to look at the shooting data as a percentage of all missed shots, which leads qualitatively to the same patterns (see Table A1 in the Appendix 6 for details).

There are many potential variables which would result in such high percentages of missed fifth shots in the last bout of shootings, including pressure, fatigue, or exhaustion. Following my hypotheses, the high failure rate of the last shot of the last bout of shootings is to a great extent due to psychological pressure. In order to explore these hypotheses, I further conducted a short qualitative questionnaire among three professional athletes (see Appendix 6 for details on the questionnaire and answers of respondents). The athletes clearly identified the fifth shot of the fourth shooting round as the one in which they experience the most pressure. They also stated that a loss of focus and starting to reflect on one's performance during a shooting increases the likelihood of performing worse.

Table 2: Missed shots in percentage of all shots (missed and not missed)

All	**1**	**2**	**3**	**4**	**5**	**All (100%)**
1^{st} bout	8.7%	8.9%	7.4%	7.4%	7.6%	8.0%
2^{nd} bout	8.6%	8.1%	6.9%	6.7%	7.9%	7.7%
3^{rd} bout	9.6%	10.6%	12.7%	12.0%	14.4%	11.9%
4^{th} bout	11.0%	11.0%	11.8%	12.2%	14.9%	12.2%
Pursuit	**1**	**2**	**3**	**4**	**5**	**Total (100%)**
1^{st} bout	8.4%	10.1%	7.5%	7.2%	7.3%	8.1%
2^{nd} bout	8.2%	7.5%	7.5%	7.1%	8.8%	7.8%
3^{rd} bout	10.0%	11.8%	13.5%	12.8%	15.2%	12.7%
4^{th} bout	11.3%	10.5%	12.7%	13.2%	14.6%	12.4%
Mass start	**1**	**2**	**3**	**4**	**5**	**Total (100%)**
1^{st} bout	9.4%	6.8%	7.2%	7.8%	8.2%	9.9%
2^{nd} bout	9.2%	9.2%	5.8%	6.2%	6.4%	9.2%
3^{rd} bout	9.0%	8.6%	11.4%	10.6%	13.0%	13.2%
4^{th} bout	10.6%	11.8%	10.2%	10.6%	15.4%	14.7%

Table 3 shows descriptive statistics of the main variables of interest. The variables are computed the following way: $missed5$ is a binary variable equal to 1 if the fifth shot of the fourth bout of shootings was missed, zero otherwise. $missed4$ is a binary variable equal to 1 if the fourth shot of the fourth bout of shootings was missed, zero otherwise. $lane$ is normalized from 0 to 1 with the formula $1 - \frac{lane_i - min(lane)}{max(lane) - min(lane)}$, so that 0 corresponds to the highest lane number and 1 corresponds to the lowest lane number. $ability$ is normalized from 0 to 1 with the formula $1 - \frac{rank_i - min(rank)}{max(rank) - min(rank)}$, so that 0 corresponds to the athlete with the lowest number of World Cup points up to the specific event and 1 corresponds to the athlete with the highest World Cup ranking of the particular discipline. $shtime$ is normalized from 0 to 1 with the formula $\frac{shtime_i - min(shtime)}{max(shtime) - min(shtime)}$, so that 0 corresponds to the fastest shooter and 1 corresponds to the slowest shooter.[10] $missedbefore5$ counts the number of missed shots of the fourth shooting bout without the last shot. $diffatime$ measures the athletes' time difference in seconds to the person directly ahead of her at the moment of reaching the final shooting bout. $atime$ is the time difference to the leader in seconds.

Table 4 shows the results of probit regressions. Column I depicts the most basic regression without any control variables: the coefficient of $lane$ is relatively large, positive and significant ($p = 0.000$). I find support for the first hypothesis: Athletes who experience higher levels of

[10] The minimum and maximum relates always to the top ten athletes at the final shooting bout.

Table 3: Descriptive statistics of the main variables

	Obs	**Mean**	**Std. Dev.**	**Min**	**Max**
$missed5$	1,350	0.149	0.356	0	1
$lane$	1,350	0.724	0.205	0	1
$shtime$	1,350	0.493	0.113	0	1
$ability$	1,350	0.825	0.202	0	1
$missed4$	1,350	0.122	0.328	0	1
$missedbefore5$	1,350	0.460	0.642	0	4
$diffatime$	1,350	3.211	4.927	0	38
$atime$	1,350	10.116	11.439	0	58

pressure due their higher position in the ranking have a higher probability of experiencing deterioration in performance. Competitors occupying the shooting lanes with the lowest numbers are those who are the fastest up to this point in the competition and are the ones who have the highest probability of finishing in the top positions. It is of vital importance for them not to miss any shots during that decisive fourth bout of shootings, as this would result in additional penalty loops. The extremely high levels of pressure that these athletes experience during that last bout of shootings peak during the last shot which leads to an increased probability of deterioration in their performance, i.e., missing the fifth shot.

Result 1: *Athletes that are on the top positions prior to the last shooting bout have a higher probability of missing the fifth shot.*

Column II tests the second hypothesis of whether longer shooting times lead to an increase in the probability of missing the fifth shot. As I have argued before, longer shooting times are probably related to less automatic execution in a precision task, which might be linked to overthinking, speculating about possible outcomes and losing one's focus. This potentially increases the probability of choking under pressure, i.e., missing the final shot. Another potential explanation would be that slower shooters are less able athletes. If such a relationship existed, we should observe a significant correlation between athletes' ability and the shooting time; results of a Pearson's correlation reveal no evidence for this ($\rho = -0.035$, $p = 0.201$, $N = 1,350$).

Result 2: *Longer shooting time is positively related to higher failure rates of the decisive final shot.*

Adding a proxy for the weather conditions (wind speed) at the time of the last shooting reveals that under more windy conditions shooting is more difficult as indicated by a significant

Table 4: Regression results for missed fifth shot of the last shooting bout

	I	II	III	IV	V
α	-2.308***	-1.641***	-1.861***	-1.995***	-1.981***
	(0.196)	(0.286)	(0.315)	(0.316)	(0.316)
$lane$	1.667***	1.642***	1.789***	1.849***	1.960***
	(0.235)	(0.236)	(0.242)	(0.240)	(0.247)
$shtime$		1.304***	1.092**	1.074**	1.193***
		(0.407)	(0.435)	(0.431)	(0.434)
$wind3$			0.170***	0.173***	0.183***
			(0.040)	(0.039)	(0.041)
$pursuit$			0.044	0.032	0.042
			(0.088)	(0.089)	(0.091)
$male$			-0.030	-0.019	-0.012
			(0.103)	(0.103)	(0.104)
$ability$			-0.261	-0.232	-0.239
			(0.201)	(0.201)	(0.205)
$missed4$			-0.161	-0.169	
			(0.120)	(0.121)	
$diffatime$			0.007	-0.014	-0.015
			(0.009)	(0.014)	(0.014)
$atime$				0.012**	0.012**
				(0.006)	(0.006)
$missedbefore5$					-0.164**
					(0.074)
N	1,350	1,350	1,350	1,350	1,350
Clusters	135	135	135	135	135
Pseudo R^2	0.047	0.058	0.077	0.080	0.084
$\chi 2$	50.484	58.599	94.701	104.583	107.825
Prob > $\chi 2$	0.000	0.000	0.000	0.000	0.000

Notes: Probit regressions with clustering on the competition level. Dependent variable is the missed fifth shot from the fourth bout of shootings; binary variable with 0 corresponding to a successful shot and 1 corresponding to a miss. *lane* relates to the athlete's ability within a competition with 0 for the last and 1 for the leading competitor. *shtime* is the normalized time for the five shots, $wind3$ is a proxy for the wind conditions at the fourth shooting bout, *ability* is an athlete's normalized world ranking, *pursuit* and *male* are dummy variables for the competition type and gender, respectively. $missed4$ is a dummy variable for missing the second to last shot and $missedbefore5$ is a variable counting the missed shots before the last one within the fourth bout of shootings. $diffatime$ and *atime* are time differences in seconds to the person directly ahead and to the leader, respectively. Standard errors are provided in parentheses. ***,** and * represent significance at the 1, 5 and 10 percent levels, respectively.

increase in missed shots. Additionally, male competitors, the competition format, ability measure, missing the penultimate shot (as a measure for a momentum effect), and the time difference to the athlete directly ahead do not seem to have a significant effect on the top performer of a competition (see Column III). The time difference to the leading athlete has a significant effect on performance which is an indicator of taking more risks to catch up the leader (see Column IV).

To take a different approach of measuring the momentum effect, I substitute the missed fourth shot with the sum of all shots before the fifth within the last shooting bout. This reveals a significant negative relationship with missing the last shot.[11] This positive momentum effect of missed shots before the last shot could be explained by the athlete regaining concentration and focusing on not missing another shot. These results are robust to alternative model specification, e.g., clustering on the individual level, adding the time difference to the athlete behind, tiredness, or interaction effects (see tables A2 and A3 in Appendix 6 for details of some specifications).

6 Conclusion

Choking under pressure is an established psychological phenomenon not only in sports competitions. In general it is difficult to figure out whether someone is not able to show the personal best performance due to pressure or inability. In professional sports competitions, athletes face severe pressure from the audience, sponsors, coaches, media, and personal expectations to show their best performance on competition days. The main challenge for the athletes is to avoid failure despite the multitude of sources of pressure.

In this paper, I analyze Biathlon World Cup data of 11 seasons to investigate whether psychological pressure leads to higher failure rates in decisive situations in a precision task (rifle shooting). The first finding suggests that leaders face the highest pressure to keep their position. Pressure peaks at the last shot of the final bout of shootings especially for the top ranked athletes resulting in an increased probability of experiencing deterioration in performance. Furthermore, longer shooting times could be an indicator for an athlete experiencing pressure through losing concentration, overthinking possible outcomes, or trying to concentrate longer to shoot better. This increases the probability of choking under pressure (i.e., missing the final shot of the final shooting round). Turning to possible momentum effects, i.e., missing one or more shots of the preceding four shots of the last shooting bout, I observe a decrease in the probability of missing the fifth shot. In other words, making a mistake could motivate athletes to concentrate more on the next shot. Results are consistent with theories on choking under pressure (Kimble and Perlmuter, 1970; Wine, 1971; Langer and Imber, 1979; Masters, 1992; Lewis and Linder, 1997) and robust when controlling for gender, competition type, weather conditions, potential tiredness, time difference to followers, restricting the analysis to athletes with a time lag to the

[11] Note that the coefficient is almost identical to *missed4* in columns III and IV.

leader which could catch up with a faultlessly executed last shooting bout if the leader misses one shot, and several interaction effects.

As mentioned above, the empirical investigation of this study is not only relevant for research in sports competitions. The applicability of the findings in a broader context, such as business and management, is also important. In today's society, with strong competition and rapid technological changes and innovations, people are forced to perform under pressure in many situations. Therefore, one may speculate about the dropout rate of high potentials in, for instance, academia, group and department leaders in firms, or so called "practice champions" in sports. This might result in large economic inefficiencies, like slower drug development, lower growth rates, or fewer world records. The feelings of stress and anxiety can affect performance and shape human behavior.

In today's society with strong competition, rapid technological changes and innovations, people are increasingly forced to perform under pressure. For example, stricter regulations in the financial industry are putting a large amount of pressure on individual decision makers. Gaining knowledge on how psychological pressure affects decisions is crucial for the development of organizational structures ensuring prudent financial decisions. Investigating the phenomenon of choking under pressure can shed further light on the causes for significant economic inefficiencies, such as dropout rates of high potentials, for instance in academia or leading positions in firms, as well as the phenomenon of "practice champions" in sports. Knowing how individuals perform under pressure conditions is also crucial for labor economists, because it offers implications for the design of incentive schemes at the workplace.

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Appendix

Appendix A: Additional Tables

Table A1: Missed shots as a percentage of all missed shots

All	**1**	**2**	**3**	**4**	**5**	**Total (100%)**
1^{st} bout	21.8%	22.2%	18.5%	18.5%	19.0%	541
2^{nd} bout	22.4%	21.3%	18.0%	17.6%	20.7%	517
3^{rd} bout	16.2%	17.9%	21.5%	20.2%	24.2%	801
4^{th} bout	18.1%	18.0%	19.3%	20.1%	24.5%	822
Pursuit	**1**	**2**	**3**	**4**	**5**	**Total (100%)**
1^{st} bout	20.6%	25.0%	18.6%	17.7%	18.0%	344
2^{nd} bout	21.0%	19.2%	19.2%	18.0%	22.5%	333
3^{rd} bout	15.8%	18.6%	21.4%	20.3%	24.0%	538
4^{th} bout	18.1%	16.8%	20.4%	21.2%	23.4%	529
Mass start	**1**	**2**	**3**	**4**	**5**	**Total (100%)**
1^{st} bout	23.9%	17.3%	18.3%	19.8%	20.8%	197
2^{nd} bout	25.0%	25.0%	15.8%	16.8%	17.4%	184
3^{rd} bout	17.1%	16.3%	21.7%	20.2%	24.7%	263
4^{th} bout	18.1%	20.1%	17.4%	18.1%	26.3%	293

Table A2: Regression results for missed fifth shot of the last shooting bout

	I	II	III	IV	V
α	-2.308***	-1.641***	-1.861***	-1.995***	-1.981***
	(0.182)	(0.273)	(0.314)	(0.303)	(0.304)
$lane$	1.667***	1.642***	1.789***	1.849***	1.960***
	(0.230)	(0.232)	(0.226)	(0.216)	(0.221)
$shtime$		1.304***	1.092**	1.074**	1.193***
		(0.398)	(0.454)	(0.452)	(0.457)
$wind3$			0.170***	0.173***	0.183***
			(0.038)	(0.038)	(0.039)
$pursuit$			0.044	0.032	0.042
			(0.087)	(0.086)	(0.084)
$male$			-0.030	-0.019	-0.012
			(0.112)	(0.112)	(0.114)
$ability$			-0.261	-0.232	-0.239
			(0.216)	(0.216)	(0.218)
$missed4$			-0.161	-0.169	
			(0.129)	(0.131)	
$diffatime$			0.007	-0.014	-0.015
			(0.008)	(0.014)	(0.014)
$atime$				0.012**	0.012**
				(0.005)	(0.005)
$missedbefore5$					-0.164**
					(0.071)
N	1,350	1,350	1,350	1,350	1,350
Clusters	225	225	225	225	225
Pseudo R^2	0.047	0.058	0.077	0.080	0.084
$\chi2$	52.557	62.917	97.803	131.236	138.667
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000

Notes: Probit regressions with clustering on the individual level. Dependent variable is the missed fifth shot from the fourth bout of shootings; binary variable with 0 corresponding to a successful shot and 1 corresponding to a miss. *lane* relates to the athlete's ability within a competition with 0 for the last and 1 for the leading competitor. *shtime* is the normalized time for the five shots, $wind3$ is a proxy for the wind conditions at the fourth shooting bout, *ability* is an athlete's normalized world ranking, *pursuit* and *male* are dummy variables for the competition type and gender, respectively. $missed4$ is a dummy variable for missing the second to last shot and $missedbefore5$ is a variable counting the missed shots before the last one within the fourth bout of shootings. $diffatime$ and *atime* are time differences in seconds to the person directly ahead and to the leader, respectively. Standard errors are provided in parentheses. ***,** and * represent significance at the 1, 5 and 10 percent levels, respectively.

Table A3: Regression results for missed fifth shot of the last shooting bout: Model I controls for persons behind, II for a potential interaction effect of gender and competition type, III for tiredness, and IV uses only athletes that are max. 20 seconds behind the leader.

	I	II	III	IV
α	-1.967***	-2.049***	-2.870***	-1.876***
	(0.316)	(0.314)	(0.794)	(0.353)
$lane$	1.785***	1.978***	1.977***	1.902***
	(0.255)	(0.246)	(0.225)	(0.278)
$shtime$	1.079**	1.255***	1.120**	1.195**
	(0.433)	(0.437)	(0.437)	(0.517)
$wind3$	0.171***	0.181***	0.173***	0.213***
	(0.039)	(0.043)	(0.042)	(0.051)
$pursuit$	0.021	0.167	0.151	0.068
	(0.089)	(0.115)	(0.136)	(0.111)
$male$	-0.013	0.156	-0.038	-0.012
	(0.103)	(0.168)	(0.106)	(0.135)
$pursuit * male$		-0.261		
		(0.185)		
$ability$	-0.240	-0.229	-0.257	-0.413
	(0.200)	(0.205)	(0.212)	(0.252)
$missed4$	-0.171			
	(0.121)			
$atime$	0.007*	0.012**	0.012**	0.013
	(0.004)	(0.006)	(0.006)	(0.023)
$btime$	0.004			
	(0.004)			
$diffatime$		-0.015	-0.015	-0.029
		(0.014)	(0.014)	(0.040)
$missedbefore5$		-0.171**	-0.170**	-0.063
		(0.074)	(0.072)	(0.083)
$tiredness$			1.643	
			(1.353)	
N	1,350	1,350	1,350	894
Clusters	135	135	358	135
Pseudo R^2	0.080	0.085	0.085	0.086
$\chi 2$	98.699	105.280	121.610	83.432
Prob $> \chi 2$	0.000	0.000	0.000	0.000

Notes: Probit regressions with clustering on the competition level. Dependent variable is the missed fifth shot from the fourth bout of shootings; binary variable with 0 corresponding to a successful shot and 1 corresponding to a miss. $lane$ relates to the athlete's ability within a competition with 0 for the last and 1 for the leading competitor. $shtime$ is the normalized time for the five shots, $wind3$ is a proxy for the wind conditions at the fourth shooting bout, $ability$ is an athlete's normalized world ranking, $pursuit$, $male$, and $pursuit * male$ are dummy variables for the competition type, gender, and the interaction effect between them, respectively. $missed4$ is a dummy variable for missing the second to last shot and $missedbefore5$ is a variable counting the missed shots before the last one within the fourth bout of shootings. $diffatime$, $atime$, and $btime$ are time differences in seconds to the person directly ahead, to the leader, and to the person on place ten, respectively. $tiredness$ serves as a proxy for how exhausting it is for an athlete, measured in the mean total time for a specific competition. Standard errors are provided in parentheses. ***,** and * represent significance at the 1, 5 and 10 percent levels, respectively.

Appendix B: Questionnaire

The names of the three questionnaire respondents are not disclosed.

The questions relate to Pursuit and Mass Start competitions. But of course feel free to bring in experiences from other competitions as well.

1. Would you say the last bout of shootings is the one in which you feel under most pressure? If not which one?
A: Yes
B: At World Cup Races I would agree. But especially at the World Championships or Olympics you have this pressure at every shot, because most of the athletes only have the chance to win a medal when they shoot clean. At a World Cup Race I am satisfied with a fourth place, at World Championships or Olympics it is the worst result.
C: Yes, the last bout of shootings is the one in which I have been under most pressure.

Now consider only the bout of shooting that was your answer to question 1.
2. During which shooting (out of the 5 shootings in the bout of shooting) do you consider yourself as under the highest level of pressure?
A: The last shoot, but the first shoot is the second difficult.
B: In most of the races it is the last one.
C: The last one.

3. How does the level of pressure develop during the 5 shootings in the bout of shooting?
A: It starts high and decreases until the fourth shot. Then the fifth shot is again very high.
B: When I can handle the pressure I keep my concentration during the 5 shots. Then it does not develop. I even do not feel the pressure. When it develops I also lose my concentration. Then most of the times I miss a target.
C: It increases towards the end of the shootings.

4. Can you describe what happens when you feel under most pressure when shooting in a competition (for example you lose concentration or you become more concentrated, you feel anxiety, you feel distracted, you feel less or more self-focused, you start thinking about avoiding failure)?
A: I lose concentration for shooting and start thinking of scenarios of what could happen if I make some mistakes. I get panicked and stop to change my shooting rhythm.
B: When I start doing, feeling or thinking, this is bad for my shooting. I try to keep my focus and I have my way to keep it. But it is difficult especially when you are tired from the race,

losing the concentration can happen very fast. Then it is sometimes a good idea to stop for a few seconds and make a "restart" of focus and concentration - when it is not too late.
C: When I am under most pressure I feel anxious and panicky.

5. What are the most common causes of pressure during shootings in a competition (for example, coming close to being first in the competition, expectations, physiological fatigue, poor preparation, opponents, presence of an audience)?
A: I feel a lot of pressure rising, when I feel that I have a very bad stand. Also the pressure rises when there are other athletes at the shootings ranges and there is a fight for the top 3 or top 6 positions.
B: All of these reasons have made me nervous at different points in my career. But since I got more stable on the track in my running times and on the shooting range as well, nervousness and pressure changed to self-confidence. I think this process never stops during a career. You always have to work hard on your performance to keep your self-confidence on a good level and things can change very fast.
C: Lack of sufficient experience and physiological fatigue.

6. How does pressure affect your shooting accuracy?
A: I make technical mistakes. For example, I start to move the weapon while pulling the trigger or I pull the trigger before having aimed at the target.
B: I think it helps me to get my highest level of accuracy. There is a certain level of concentration that I can reach only in competitions. I think it is the adrenaline before the race. But the pressure can also cause a very low level of accuracy.
C: Pressure is the main factor influencing shooting accuracy.

Thank you!

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Florian Lindner

Choking under pressure of top performers: Evidence from biathlon competitions

Abstract

Psychological pressure affects performance. This is especially true for individuals completing precision tasks in decisive situations, such as assessment tests, job talks, or sports competitions. In this paper, I shed light on detrimental effects of pressure on performance, a phenomenon known as "choking under pressure". I analyze a unique setting in which the effect of pressure on performance is naturally observable: Biathlon World Cup competitions. As the last shot in the final bout of shootings is regularly decisive for the victory, pressure is highest on the leader of the competition not to miss this last shot. Using event data from 11 seasons of Biathlon World Cup, I find strong evidence for "choking under pressure", implying that especially leaders are more likely to fail decisive shots. Furthermore, taking more time for the last shootings bout leads to a decrease in performance. Finally, I show suggestive evidence for a momentum effect â€“ after missing a shot during the last shooting bout, the probability of missing the last shot decreases.

ISSN 1993-4378 (Print)
ISSN 1993-6885 (Online)