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Prospect theory and psychological factors in football: Effects of the video assistant referee on penalty conversion rates in the German Bundesliga

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Prospect Theory and Psychological Factors in Football Effects of the Video Assistant Referee on Penalty Conversion Rates in the German Bundesliga

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Abstract

The increasing integration of technological aids, such as the video assistant referee (VAR), is fundamentally transforming decision-making processes in professional football, especially influencing critical match moments. Penalty kicks, characterised by technical simplicity but intense psychological pressure, may be particularly affected by delays caused by VAR reviews. An analysis of 737 penalty kicks in the German Bundesliga and second Bundesliga (2019-2023) reveals that penalties confirmed following VAR interventions show significantly lower conversion rates. This impact is especially pronounced during the early stages of matches, suggesting prolonged delays disrupt players' established pre-performance routines and heighten psychological stress, which aligns with prospect theory's insights on decision-making under uncertainty. Thus, these insights emphasise how technological innovations enhance officiating accuracy and introduce new psychological demands on athletes at the same time.

JEL Codes: D81, D91, L83, Z20, Z21

Keywords: Bias, Football, Penalty, Rule, VAR

Prospect-Theorie und psychologische Faktoren im Fußball Auswirkungen des Video-Assistenten-Schiedsrichters auf Elfmeter-Erfolgsquoten in der deutschen Bundesliga

Zusammenfassung

Der Einsatz technischer Hilfsmittel, wie des Videoschiedsrichters (VAR), verändert zunehmend die Entscheidungsprozesse im Profifußball und beeinflusst damit auch die Dynamik entscheidender Spielsituationen. Insbesondere beim Elfmeterschießen, einer scheinbar einfachen technischen Aktion mit erheblicher psychologischer Komplexität, können Verzögerungen durch VAR-Überprüfungen erhebliche Auswirkungen auf die Leistung der Spieler haben. Eine Untersuchung von 737 Elfmetern in der 1. und 2. Bundesliga (2019-2023) zeigt, dass besonders Elfmeter, die nach einer VAR-Überprüfung bestätigt werden, eine niedrigere Erfolgsquote aufweisen. Dieser Effekt tritt insbesondere in frühen Spielphasen auf, wo lange Wartezeiten möglicherweise die Routinen der Spieler stören und zusätzlichen psychologischen Druck erzeugen, was mit den Erkenntnissen der Prospect-Theorie zur Entscheidungsfindung unter Unsicherheit übereinstimmt. Die Untersuchung liefert wertvolle Erkenntnisse darüber, wie technologische Veränderungen Schiedsrichterentscheidungen verbessern und zugleich neue psychologische Herausforderungen für Sportler schaffen.

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Prospect Theory and Psychological Factors in Football Effects of the Video Assistant Referee on Penalty Conversion Rates in the German Bundesliga

1. Introduction

The implementation of technological aids to support officiating decisions represents a significant evolution in modern sport. In football, the video assistant referee (VAR) has fundamentally altered officiating processes since its implementation across major leagues worldwide. While research has examined VAR's effectiveness in reducing clear errors (Spitz et al. 2021), limited attention has been given to its psychological impact on player performance.

Penalty kicks represent decisive moments in football matches that combine technical simplicity with extraordinary psychological complexity. While striking a stationary ball from 11 meters appears to be a straightforward technical action, professional players frequently miss, as psychological factors and competitive pressure significantly influence success rates (Jordet et al. 2007). This performance variability underscores the substantial psychological factors influencing execution under match conditions. When VAR reviews potential penalty incidents, it can create significant delays between the incident and penalty execution (Spitz et al. 2021), potentially disrupting established pre-performance routines and introducing additional psychological pressure in already high-stakes situations.

Behavioural economics, particularly prospect theory (Kahneman & Tversky 1979), provides a valuable framework for understanding how these technologically induced delays might influence player performance through mechanisms such as loss aversion and reference-dependent framing of the penalty situation.

The impact of external interruptions on skilled performance can also be understood through attentional theories, which suggest that well-practiced skills are optimally performed when executed automatically through implicit processing systems (Beilock & Carr 2001, Masters 1992). Such interruptions, particularly those that increase pressure and anxiety, may disrupt this automaticity by triggering explicit monitoring processes, thereby diminishing performance quality (Masters & Maxwell 2008). These effects may vary considerably depending on contextual factors including temporal position within the match and the immediate competitive situation (Almeida & Volossovitch 2023, Hill & Shaw 2013, Jordet et al. 2007).

While the academic literature has extensively examined both penalty kick performance (Jordet et al. 2007, Memmert et al. 2013) and the technical implementation of VAR (Lago-Peñas et al. 2019, Spitz et al. 2021), limited research has investigated how VAR-induced delays affect penalty performance. Veldkamp and Koning (2023) examine the influence of VAR on penalty conversion rates across various European leagues. They find that VAR interventions significantly reduce the probability of successful penalties, regardless of the waiting time between foul and execution. Our study extends this approach by specifically differentiating between different types of VAR interventions and considering the temporal context within matches.

By analysing 737 penalties across the seasons 2019/2020 to 2022/2023 in the Bundesliga and second Bundesliga, we investigate whether penalties following VAR reviews show different success rates compared to non-reviewed penalties, and how these effects vary across different match phases. Understanding these effects has implications beyond penalties and football, as technological officiating aids become increasingly prevalent across sports, making their psychological impact on performers crucial knowledge for players, coaches, and governing bodies.

2. Theoretical Background

The psychological complexity of penalty kicks has made them an important research subject despite their apparent technical simplicity. With professional conversion rates consistently around 75 to 80 % (Almeida et al. 2016, Chiappori et al. 2002, Palacios-Huerta 2003), penalties represent a unique combination of technical skill and psychological resilience. Under pressure, failure rates demonstrably increase, as supported by prior research (Jordet & Hartman 2008, Jordet et al. 2012), which highlights how psychological factors significantly influence performance under competitive pressure.

To better understand the conversion rate of penalty kicks, it is helpful to consider the underlying mathematical principles. Ludwig (2008) proposes two primary approaches. The first is the probabilistic (or "gambling") model, which assumes that the kicker deliberately aims at one of the four corners of the goal. Accordingly, the goalkeeper has a 25 % chance of guessing correctly. If the centre of the goal is included as a possible target, the probability of a successful save decreases even further.

The second approach is the spatial coverage model: A football goal measures 7.32 meters in width and 2.44 meters in height, yielding a total area of 17.86 m². A goalkeeper of average height (1.90 m) and arm span (1.90 m) can cover approximately 25% of the goal area while

standing. This area includes a rectangle $(1.60 \text{ m} \times 1.90 \text{ m})$ and a semicircle with a radius of 0.95 m, formed by the goalkeeper's arm reach. This purely geometric coverage aligns with empirically observed historical penalty conversion rates (Ludwig 2008).

Another important factor is the temporal dynamics of the penalty situation: At average shot speeds, the ball reaches the upper corners of the goal within 0.42 to 0.58 seconds, while a goal-keeper's reaction time is approximately 0.2 seconds. This means that goalkeepers often have no physical chance to save a well-placed shot to the upper corners, making professionally executed penalties almost impossible to stop (Ludwig 2008).

Previous research on in-game penalty kicks has identified three key categories of factors influencing success: individual characteristics, situational conditions, and performance-related aspects (Almeida et al. 2016, Almeida & Volossovitch 2023). Situational factors refer to external conditions that shape the immediate context of the penalty, rather than the attributes of the kicker (Newell 1986). These include pre-game constraints such as home/away (dis-)advantage and in-game constraints like the current score and match timing. This study focuses on how match minute combined with VAR interventions influence performance under pressure.

The impact of pressure on performance has been widely examined through dual-process theories, particularly the default-interventionist model, which differentiates between automatic and controlled processing in skilled motor execution. Research indicates that performance declines often occur when pressure forces athletes to transition from automatic to controlled processing, resulting in breakdowns in execution (Furley et al. 2015). Well-learned skills like penalty kicks typically rely on proceduralised motor patterns executed with minimal conscious control. This automaticity enables fluid, coordinated movements by minimising the cognitive load associated with explicit monitoring, allowing athletes to maintain efficiency in performance (Masters & Maxwell 2008). However, studies on skilled motor performance suggest that when such actions become overly monitored, especially under pressure, performance can deteriorate (Beilock & Carr 2001).

Evidence in sports demonstrates that performance deteriorates when athletes shift from automatic to conscious processing, as documented by Zachry et al. (2005) in basketball free throws and by Wulf (2013) across various precision sports. This phenomenon, known as "choking under pressure", represents a significant decline in performance despite high motivation to succeed (Baumeister 1984). To explain this disruption, reinvestment theory provides a framework for understanding how pressure interferes with automatic execution. It describes how performers under pressure consciously monitor previously automated movements, leading to performance breakdowns (Masters & Maxwell 2008). Several mechanisms trigger reinvestment, including heightened self-consciousness, explicit monitoring of movement mechanics, and disruption of pre-performance routines. Laboratory studies consistently show that increased evaluation apprehension promotes self-focused attention, further interfering with automatic execution (Masters & Maxwell 2008).

Pre-performance routines help athletes regulate attentional focus and maintain mental readiness for executing skills under pressure (Moran 1996). These routines assist in controlling arousal, directing attention to task-relevant cues, and preventing disruptive conscious control (Cotterill 2010). However, extreme pressure can challenge routine adherence. Jordet and Hartman (2008) find that players in high-pressure penalty shootouts often shortened their preparation time as an avoidance response to stress, correlating with lower success rates, suggesting that reducing preparation time may impair performance.

A VAR intervention introduces an external disruption with additional delay and uncertainty to the process, altering the psychological conditions for penalty takers. VAR reviews can be categorised into two types:

- 1. **Type 1 interventions**: A penalty initially awarded by the on-field referee undergoes VAR confirmation, creating uncertainty for the shooter.
- 2. **Type 2 interventions**: A penalty is awarded only after VAR review, meaning the shooter begins preparation after the decision is finalised.

These different review types impose distinct psychological demands. When a penalty undergoes a Type 1 VAR review, players experience an extended waiting period of uncertainty, which can disrupt routines and increase anxiety. Research indicates that individuals prefer resolving anticipated events quickly rather than enduring prolonged waiting periods, particularly in stressful situations (Berns et al. 2006). This prolonged uncertainty may shift focus from automatic execution to conscious control, a known cause of performance decline (Beilock & Carr 2001, Masters & Maxwell 2008). While shorter, self-imposed preparation times are often linked to poorer execution, externally imposed delays can also negatively affect performance when prolonged (Jordet et al. 2009).

However, an extended waiting period might also provide benefits. Cotterill (2010) suggests that additional preparation time may help athletes stabilise arousal and reinforce routines,

potentially improving execution. Research on task interruptions indicates that predictability plays a crucial role in cognitive load and task resumption (Trafton et al., 2003). Predictable interruptions allow for preparatory goal encoding and rehearsal, reducing cognitive disruption, whereas sudden interruptions impose higher working memory demands and delay resumption. In contrast, when a penalty is newly awarded after a VAR review (a Type 2 intervention), the preparation process begins only after the decision is confirmed, potentially preserving automaticity like penalties without VAR involvement. Veldkamp and Koning (2023) find that VAR interventions significantly decrease the probability of successful penalties, regardless of the waiting time between foul and penalty execution. They argue that the uncertainty associated with VAR reviews creates a psychological disadvantage for penalty takers, though they do not differentiate between different types of interventions.

In this context, several key concepts from behavioural economics help explain the behaviour of penalty takers under the influence of VAR interventions. According to classical decision theory (von Neumann & Morgenstern 1944), a player should make a rational choice regarding shot placement and technique based on probabilities and the expected utility of scoring. However, a VAR intervention can alter the perceived context of the situation, introducing cognitive uncertainty and leading to systematic deviations from rational decision-making.

Moreover, the status quo bias (Samuelson & Zeckhauser 1988) plays a role: Players tend to stick to familiar routines because altering them entails cognitive costs. A VAR intervention disrupts established routines and forces players to re-evaluate their behaviour, increasing uncertainty and potentially impairing performance.

The anchoring effect (Tversky & Kahneman 1974) may also be relevant. Players might subconsciously anchor their decision-making to external cues, such as average conversion rates or the nature of the VAR review. A VAR intervention, particularly if prolonged or controversial, could bias the player's perception of the penalty situation.

Most notably, prospect theory (Kahneman & Tversky 1979) offers a compelling framework:

- Loss aversion: Following a VAR confirmation (Type 1), the fear of missing may intensify, as the event becomes more salient. Players tend to weigh potential losses (missed penalties) more heavily than equivalent gains (successful conversions).
- Framing effects: A penalty that is confirmed by VAR (Type 1) may be perceived as a second chance or as added pressure, depending on the player's mindset. Conversely, a

penalty awarded via VAR (Type 2) may be interpreted as an unexpected gain, potentially reducing perceived pressure and enabling more composed execution.

These behavioural mechanisms offer a well-founded explanation for why VAR interventions can influence not only the physical dynamics of penalty kicks but also their psychological dimensions.

Situational factors, such as the temporal context within competitions, may moderate the impact of VAR, leading to systematic variations across different match phases. A VAR review in the final minutes may be perceived as more stressful than an early-game review due to heightened outcome importance. Cerin et al. (2000) propose an interactional model of stress that integrates temporal dimensions, highlighting how emotional responses evolve throughout competition. As the conclusion of an event approaches, emotional intensity may increase due to shifting appraisals of situational importance. Empirical findings on penalty performance suggest that match timing plays a significant role in success rates, though with contradictory evidence. Almeida et al. (2016) find higher success rates during the first and last 30 minutes, while Chiappori et al. (2002) report declining success towards the final minutes, possibly due to accumulating fatigue or heightened psychological stress. These discrepancies highlight the complexity of temporal effects, suggesting that both individual and situational factors influence how VAR reviews are perceived and their potential impact on performance.

The ability to convert penalty kicks can be decisive in determining match outcomes, especially in elimination rounds (Almeida et al. 2016, Bar-Eli & Azar 2009). Research on psychological stress provides insights into why penalty performance may fluctuate under pressure. Lazarus (2000) highlights that stressor appraisals are shaped by changing environmental conditions and personal stakes. Hill and Shaw (2013) outline key theoretical perspectives on "choking under pressure", emphasising that performance breakdowns in high-stakes situations are influenced by both self-focus and distraction mechanisms, which are moderated by individual and situational factors. Their research finds that performance deterioration is particularly pronounced when multiple pressure sources combine (e.g., evaluation pressure and outcome pressure), a scenario frequently present in VAR-reviewed penalties during critical match situations. Supporting this, Jordet and Hartman (2008) report that players facing high-pressure penalty kicks display distinct avoidance behaviours, such as reduced preparation time and a tendency to avert their gaze from the goalkeeper. However, Almeida et al. (2016) find that the current score did not significantly influence penalty success rates, suggesting that other situational and psychological variables play a greater role.

The implementation of VAR creates unique challenges for penalty takers through multiple psychological mechanisms: disruption of automaticity through increased evaluation awareness, triggering of reinvestment processes during extended preparation periods, interference with established routines, and modification of attentional control under pressure. These effects logically vary across contexts (intervention types, match phases, and competitive situations) through established psychological processes related to cognitive load, temporal pressure, and challenge-threat appraisals. The systematic examination of these variations provides not only insight into penalty performance under technological officiating, but also broader understanding of how technological interventions affect skilled performance across sporting contexts.

3. Hypotheses

Building on the theoretical background discussed in the previous chapter, we derive two hypotheses that we empirically test in the following analysis. The first aspect under investigation is whether the type of VAR intervention affects penalty conversion rates. Type 1 interventions, where a penalty decision undergoes review before confirmation, create a prolonged period of uncertainty, potentially increasing cognitive load and self-focus. In contrast, Type 2 interventions, where a penalty is awarded only after review, allow for a structured preparation process. Given that uncertainty, preparation time and routines are key factors influencing performance under pressure, we expect that penalties taken after Type 1 interventions will have lower success rates than those taken after Type 2 interventions or without VAR involvement:

H1: Penalties following Type 1 VAR interventions will demonstrate lower conversion rates than penalties following Type 2 VAR interventions or without VAR involvement.

Next, we assess whether the effect of VAR interventions varies across different match phases. As stress responses and fatigue accumulate over the course of a match, performance under pressure may fluctuate. Previous research suggests that penalty success rates can differ across match phases, with some evidence indicating higher conversion rates in the early and late periods of a match, while other studies report a decline in success rates towards the final minutes. Since VAR interventions impose an additional psychological burden, their disruptive effects may be stronger in specific match phases:

H2: The effect of VAR interventions on penalty conversion rates varies systematically across different phases of the match.

These hypotheses provide testable predictions about how VAR influences penalty performance across different contexts in professional football.

4. Data

This study utilises a unique dataset of 737 penalty kicks from German professional football leagues between the 2019/2020 and 2022/2023 seasons. The sample comprises 376 penalties (51.02 %) from the Bundesliga (first division) and 361 penalties (48.98%) from the second Bundesliga (second division). Data were collected from three primary sources: (1) penalty kick information from transfermarkt.de, (2) VAR intervention details from the official Bundesliga website using a Python 3 web scraping algorithm, and (3) betting market data from football-data.co.uk.

The dependent variable in our analysis is penalty kick success (coded 1 for successful conversion, 0 for unsuccessful). The primary independent variables focus on VAR intervention types: Type 1 interventions (20.22 % of cases) occur when a referee's initial penalty decision undergoes VAR review before confirmation, creating a waiting period for the kicker. Type 2 interventions (26.05 % of cases) represent situations where VAR review led to a penalty being awarded after the referee initially made no such call. The remaining 53.73 % of penalties were awarded without VAR involvement.

To test our temporal hypothesis, we use the match minute when the penalty occurred. The dataset also includes several control variables that prior research has identified as influential in penalty outcomes: goal difference (prior to the penalty), penalty team (home or away), attendance figures (measured in thousands), league level and betting odds differential (measuring relative team strength). We generated phase variables to categorise match periods (early: 1-30 minutes, mid: 31-60 minutes, late: 61-90 minutes). Additionally, for the analysis of goal difference effects, we created specialised variables to identify penalties taken in high-pressure situations, indicating whether the penalty taker's team was trailing, leading, or drawing at the time of the penalty.

Our dataset encompasses a unique period that includes the COVID-19 pandemic, with 36.91 % of matches played without spectators ("ghost games") and 63.09 % with audiences. This provides a natural experiment to examine performance under different environmental conditions.

Data cleaning procedures included standardising time formats and cross-referencing VAR interventions with penalty reports. All data operations and statistical analyses were performed in Stata, with logistic regression as the primary analytical approach given the binary nature of our dependent variable.

5. Empirical Results

5.1. Descriptive Statistics

Table 1 presents data on 737 observations, covering various factors related to penalty events and match conditions. *PenaltySuccess* indicates whether a penalty was scored, with an average success rate of 78.7 %. *VARType* classifies the type of video assistant referee intervention, ranging from no intervention (0) to confirmation (1) or awarding of a penalty (2). *MatchMinute* records the time of the event. Other variables include *HomeTeam*, which identifies whether the penalty taker's team was playing at home, *ScoreDifference*, capturing the goal margin at the time of the event and *Attendance*, reflecting the number of spectators. *OddsDisparity* measures differences in betting odds to measure the relative strength of the teams and *COVID* indicates whether the match occurred during the pandemic.

Variable	Ν	Mean	Std. Dev.	Min	Max
PenaltySuccess	737	0.787	0.410	0	1
VARType	737	0.723	0.850	0	2
MatchMinute	737	51.138	25.824	2	90
HomeTeam	737	0.442	0.497	0	1
ScoreDifference	737	-0.099	1.296	-5	5
Attendance	737	17,820.83	20,954.89	0	81,365
OddsDisparity	737	0.741	4.248	-19.74	23.6
COVID	737	0.369	0.483	0	1

Note: Success = Penalty success (0 = miss, 1 = goal), VARType = VAR intervention type (0 = No VAR, 1 = VAR confirms penalty, 2 = VAR awards penalty), HomeTeam = Penalty awarded team (0 = away, 1 = home); Score-Difference = Goal difference before penalty.

Table 1: Descriptive Statistics

To investigate Hypothesis 1 and based on the theoretical assumption that Type 1 interventions have a different psychological impact on the penalty taker compared to both Type 2 interventions and penalties without VAR involvement, we created the variable *VARBinary*, coded as 0 (no VAR or Type 2 intervention) and 1 (Type 1 intervention). Table 2 presents penalty success rates by different contextual factors.

Factor	Category	Success Rate (%)	Chi-square p-value
VARType	Гуре No VAR		0.368
	VAR Type 1 (confirms penalty)	74.50	
	VAR Type 2 (awards penalty)	80.21	
VARBinary	Other penalties	79.76	0.161
	VAR Type 1 (confirms penalty)	74.50	
League	Bundesliga	79.79	0.461
	Second Bundesliga	77.56	
COVID	No COVID	78.92	0.844
	COVID	78.31	
Match Phase	Early (1-30)	74.62	0.246
	Mid (31-60)	80.91	
	Late (61-90)	79.60	
Match Situation	Leading	81.15	0.377
	Tied	79.46	
	Trailing	75.90	

Note: p-values from Pearson's chi-square test.

Table 2: Penalty Success Rates by Key Factors

Initial descriptive analysis reveals several interesting patterns. The penalty success rates across different VAR intervention types do not show statistically significant differences, although penalties confirmed by VAR have a somewhat lower success rate (74.50 %) compared to those awarded by VAR (80.21 %) or without VAR involvement (79.55 %). Similarly, no significant differences are observed between leagues, COVID-affected matches, match phases or match situations. Penalties taken during the middle phase of matches (31-60 minutes) show the highest success rate at 80.91 %, compared to 74.62 % in the early phase (1-30 minutes) and 79.60 % in the late phase (61-90 minutes). This suggests that players may perform more effectively from the penalty spot during the middle third of matches, though the chi-square p-value of 0.246 indicates that these differences are not statistically significant. To provide a more nuanced temporal analysis and explore potential interactions with VAR decisions, Figure 1 presents success rates by 10-minute intervals and VAR status, revealing patterns in how penalty success varies over the course of a match. The intervals were created by grouping match minutes into standardised 10-minute periods (0-9, 10-19, 20-29, etc.) with any stoppage time beyond the 90th minute included in the final interval.

The graph illustrates a temporal pattern: penalties following VAR confirmation show notably lower success rates in the early match phases compared to other penalties. This gap gradually

diminishes as the match progresses, and by the later stages, the success rates between the two groups converge. This descriptive observation suggests a potential temporal component to the VAR effect that warrants further investigation in our regression analysis.



Figure 1: Penalty Success Rate by Match Time and VAR Use

Figure 2 illustrates the relationship between penalty success rates and score difference, complementing the temporal analysis in Figure 1 by controlling for match context. The consistent gap between VAR-confirmed and other penalties across most score differentials indicates that the observed temporal VAR effect is independent of score distribution throughout match progression, with extreme score differences excluded due to insufficient sample size.



Figure 2: Penalty Success Rate by Score Difference and VAR Use

5.2. Analysis

Our analysis employs logistic regression models to investigate the relationship between VAR confirmation and penalty success. Since penalty outcomes are binary (missed = 0, scored = 1), we used binary logistic regression with control variables including match minute, score difference, home team advantage, league level, attendance, and odds disparity, factors that could influence player performance under pressure. To explore the temporal component shown in Figure 1, we included interactions with match timing and differences between VAR intervention types. The binary logistic regression equation is specified as:

$$P(Y = 1) = 1 \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_j (x_m \times x_n) + \beta_k x_k)}}$$

Y is the binary dependent variable (*PenaltySuccess*), β_0 is the intercept, *e* is the base of the natural logarithm, β_1 , β_2 , ..., β_k are the coefficients estimated by the logit model, and x_1 , x_2 , ..., x_k are the independent variables. Table 3 presents our main models.

Model 1 shows that VAR-confirmed penalties (*VARBinary*, which compares VAR Type 1 confirmations against all other penalties) have a significant negative effect on conversion probability. After adding match-related control variables in Model 2, these relationships remain stable, indicating their robustness across specifications. The interaction term between VAR confirmation and match minute suggests that this negative effect diminishes as the match progresses, although this interaction effect only approaches conventional levels of statistical significance (p < 0.1). Notably, compared to preliminary models without interaction terms (not shown), the inclusion of the match minute interaction reveals a suppressor effect: the *VARBinary* coefficient increases both in magnitude and statistical significance (from p < 0.15 to p < 0.05). This highlights the importance of accounting for temporal dynamics when estimating the true impact of VAR confirmations on penalty outcomes.

To isolate specific VAR effects, Models 3 and 4 compare only VAR Type 1 decisions against penalties without any VAR intervention. These models show significant negative effects similar to those in Model 1 and 2, confirming that VAR Type 1 confirmations specifically reduce conversion probability. Consistent with Models 1 and 2, the interaction term shows weak statistical significance (p < 0.1). In contrast, Models 5 and 6, which compare VAR Type 2 decisions against penalties without VAR intervention, reveal non-significant coefficients of smaller magnitude, suggesting differential effects across VAR types.

	(1)	(2)	(3)	(4)	(5)	(6)
VARBinary	-1.097**	-1.094**				
	(0.019)	(0.020)				
MatchMinute	0.002	0.002	0.001	0.000	0.001	0.000
	(0.608)	(0.615)	(0.923)	(0.968)	(0.901)	(0.935)
VARBinary × MatchMinute	0.015^{*}	0.015^{*}				
	(0.069)	(0.070)				
ScoreDifference	0.117	0.125	0.104	0.091	0.127	0.139
	(0.112)	(0.110)	(0.204)	(0.298)	(0.129)	(0.117)
HomeTeam	-0.188	-0.197	-0.254	-0.213	-0.244	-0.275
	(0.304)	(0.306)	(0.232)	(0.336)	(0.244)	(0.216)
Attendance (thousands)		0.008		0.020^{**}		0.005
		(0.204)		(0.024)		(0.524)
OddsDisparity		-0.006		0.023		-0.015
		(0.816)		(0.428)		(0.598)
League		-0.028		0.028		-0.057
		(0.888)		(0.903)		(0.800)
COVID		0.207		0.306		0.098
		(0.409)		(0.295)		(0.732)
VARType (Type 1)			-1.154**	-1.168**		
			(0.019)	(0.019)		
VARType (Type 1) × MatchMinute			0.017^{*}	0.017^{*}		
			(0.055)	(0.054)		
VARType (Type 2)					-0.172	-0.199
					(0.723)	(0.685)
VARType (Type 2) × MatchMinute					0.005	0.005
					(0.563)	(0.549)
Constant	1.375***	1.181***	1.459***	1.011^{**}	1.450***	1.407***
	(0.000)	(0.001)	(0.000)	(0.014)	(0.000)	(0.001)
N	737	737	545	545	588	588
Pseudo R ²	0.015	0.018	0.018	0.031	0.008	0.010

Note: p-values in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01; VARBinary = 1 for penalties confirmed by VAR after initial award, 0 otherwise; (1) main model with situation-specific control variables; (2) includes match-related control variables; (3) VAR Type 1 only with situation-specific control variables; (4) VAR Type 1 only including match-related control variables; (5) VAR Type 2 only with situation-specific control variables; (6) VAR Type 2 only including match-related control variables.

Table 3: Logistic Regression Models for Penalty Success

These findings support our first hypothesis by demonstrating that the two types of VAR interventions have distinctly different effects on penalty success. Type 1 interventions significantly reduce success rates, while Type 2 interventions do not differ significantly from penalties without VAR involvement. Figure 3 visualises the predicted success probabilities by match minute for all three categories.



Figure 3: Predicted Penalty Success Probability by Match Minute and VAR Review Type

The graph illustrates that Type 1 VAR interventions have lower predicted success probabilities in early match phases compared to both No VAR and Type 2 VAR interventions. As the match progresses, these differences diminish, with all three categories converging toward similar success probabilities by the end of the match.

To further investigate the temporal variation in VAR effects suggested by Model 2, we calculated the marginal effects of VAR confirmation at different match minutes. Table 4 presents these estimated effects, showing how the impact of VAR on penalty success probability changes throughout the match duration.

MatchMinute	Marginal Effect	Std. Err.	Z	P > z	[95% Conf. Interval]
10	-0.195**	0.089	-2.19	0.028	-0.369; -0.021
20	-0.157**	0.071	-2.21	0.027	-0.297; -0.018
30	-0.122**	0.056	-2.16	0.030	-0.232; -0.011
40	-0.088^{*}	0.045	-1.94	0.053	-0.177; 0.001
50	-0.057	0.040	-1.41	0.160	-0.136; 0.022
60	-0.028	0.041	-0.69	0.490	-0.108; 0.052
70	-0.002	0.045	-0.05	0.956	-0.090; 0.085
80	0.021	0.050	0.41	0.680	-0.077; 0.118
90	0.041	0.055	0.74	0.456	-0.066; 0.148

Note: Marginal effects represent the change in probability of penalty success associated with VARBinary at different match minutes, based on Model 2 in Table 3. * p < 0.1, ** p < 0.05, *** p < 0.01.

Table 4: Marginal Effects of VAR Confirmation by Match Minute

The marginal effects analysis reveals that VAR confirmation has a significant negative effect on penalty success in the early stages of the match (minutes 10, 20, and 30), with the effect gradually diminishing and eventually becoming slightly positive (though not significantly) in the later stages. At minute 10, VAR confirmation is associated with a 19.5 percentage point decrease in the probability of success (p = 0.028). By minute 30, this negative effect decreases to 12.2 percentage points (p = 0.030). After minute 40, the effect is mostly not statistically significant, with minute 40 showing a marginally significantly negative effect (p = 0.053).

To deepen the analysis of temporal and situational patterns in our data, Table 5 incorporates categorical variables. Specifically, we replaced *MatchMinute* with *MatchPhase* categories (Early, Mid, Late) and substituted *ScoreDifference* with *MatchSituation* categories (Tied, Trailing, Leading) to provide a more structured understanding of how these contextual factors influence penalty success. In these models, the early match phase and leading match situation serve as reference categories.

The results strengthen our earlier findings while providing additional insights. Models 1 and 2 show that penalties subject to Type 1 VAR confirmation have significantly lower success rates than other penalties ($\beta = -1.058$, p = 0.008 without controls; $\beta = -1.068$, p = 0.007 with controls), with this coefficient representing the effect in the early match phase (the reference category).

The interaction terms between *VARBinary* and middle phase ($\beta = 1.109$, p = 0.054) and late phase ($\beta = 1.011$, p = 0.054) represent the difference in the VAR effect between these phases and the early phase. While these interactions are statistically significant at the 10 % level but not at the 5 % level (p = 0.054), their positive coefficients suggest the negative impact of VAR confirmation observed in the early phase diminishes in later phases.

When examining VAR types separately (Models 3-6), we find similar results. Type 1 interventions (Models 3 and 4) show significant negative effects in the early match phase, with a positive interaction coefficient with middle and late phase significant at the 10 % level in both models. As in Table 3, Type 2 interventions (Models 5 and 6) demonstrate no significant main effects or interactions across any match phase, confirming the distinct psychological mechanisms we theorised for these different intervention types.

These findings provide robust evidence supporting our hypotheses, demonstrating that VAR confirmation negatively affects penalty success rates. The results suggest this effect is most pronounced during early match phases and gradually diminishes as matches progress.

	(1)	(2)	(3)	(4)	(5)	(6)
VARBinary	-1.058***	-1.068***				
	(0.008)	(0.007)				
MatchPhase (Middle)	0.186	0.190	0.172	0.173	0.147	0.143
	(0.488)	(0.481)	(0.597)	(0.600)	(0.651)	(0.661)
MatchPhase (Late)	0.155	0.160	0.212	0.197	0.151	0.142
	(0.560)	(0.551)	(0.508)	(0.545)	(0.637)	(0.657)
VARBinary x MatchPhase (Mid)	1.066^{*}	1.109^{*}				
	(0.063)	(0.054)				
VARBinary x MatchPhase (Late)	1.003^{*}	1.011^{*}				
	(0.056)	(0.054)				
MatchSituation (Tied)	-0.005	0.016	0.097	0.174	-0.040	-0.036
	(0.984)	(0.949)	(0.731)	(0.544)	(0.902)	(0.900)
MatchSituation (Trailing)	-0.292	-0.291	-0.296	-0.220	-0.293	-0.310
	(0.225)	(0.244)	(0.282)	(0.444)	(0.296)	(0.289)
HomeTeam	-0.205	-0.211	-0.266	-0.230	-0.273	-0.293
	(0.264)	(0.278)	(0.211)	(0.302)	(0.189)	(0.188)
Attendance (thousands)		0.009		0.021**		0.005
		(0.178)		(0.017)		(0.530)
OddsDisparity		-0.004		0.022		-0.010
		(0.874)		(0.461)		(0.716)
League		-0.037		0.030		-0.057
		(0.849)		(0.894)		(0.799)
COVID		0.209		0.320		0.108
		(0.407)		(0.278)		(0.708)
VARType (Type 1)			-1.037**	-1.085**		
			(0.013)	(0.010)		
VARType (Type 1) × MatchPhase (Mid)			1.096*	1.190^{*}		
			(0.069)	(0.051)		
VARType (Type 1) × MatchPhase (Late)			0.994^{*}	1.042^{*}		
			(0.071)	(0.062)		
VARType (Type 2)					0.063	0.042
					(0.881)	(0.922)
VARType (Type 2) × MatchPhase (Mid)					0.077	0.075
					(0.893)	(0.897)
VARType (Type 2) × MatchPhase (Late)					-0.029	-0.014
					(0.958)	(0.980)
Constant	1.452***	1.236***	1.397***	0.864^{*}	1.486***	1.428***
	(0.000)	(0.001)	(0.000)	(0.057)	(0.000)	(0.001)
N	737	737	545	545	588	588
Pseudo R ²	0.018	0.021	0.024	0.038	0.007	0.008

Note: p-values in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01; VARBinary = 1 for penalties confirmed by VAR after initial award, 0 otherwise; (1) model with situation-specific control variables and match phase interaction; (2) includes match-related control variables; (3) VAR Type 1 only with situation-specific control variables and match phase interaction; (4) VAR Type 1 only including match-related control variables and match phase interaction; (5) VAR Type 2 only with situation-specific control variables and match phase interaction; (6) VAR Type 2 only including match-related control variables and match phase interaction; (6) VAR Type 2 only including match-related control variables and match phase interaction. Match phase categories: Early (minutes 1-30), Mid (minutes 31-60), Late (minutes 61-90) with Early as reference category. Match situation categories: Leading, Tied, Trailing with Leading as reference category.

Table 5: Logistic Regression Models by Match Phase and Match Situation

6. Discussion

In the following, we first discuss our hypotheses and their implications before reflecting on broader considerations regarding VAR's influence on penalty performance.

H1: Penalties following Type 1 VAR interventions will demonstrate lower conversion rates than penalties following Type 2 VAR interventions or without VAR involvement.

Our results provide robust support for this hypothesis. Penalties subjected to a Type 1 review exhibit lower conversion rates compared to both Type 2 interventions and penalties without VAR involvement. This effect appears influenced by the match timing and to be driven not by the VAR technology itself but by the specific psychological condition created: prolonged uncertainty trough additional waiting time during an already high-pressure moment. This interpretation aligns with reinvestment theory (Masters & Maxwell 2008) and attentional control models of performance under pressure.

In contrast, Type 2 interventions, where preparation commences only after decision certainty, show conversion rates statistically indistinguishable from non-VAR penalties. This striking difference between intervention types provides compelling evidence that uncertainty, rather than technological involvement per se, is the critical factor affecting performance. Regarding the framing effect, Type 1 interventions frame the penalty as something that could have been lost, creating psychological pressure to "not waste" the confirmed opportunity. Type 2 interventions (VAR-awarded penalties), by contrast, are framed as gains or "new" opportunities which are often perceived with less pressure and therefore show conversion rates statistically indistinguishable from non-VAR penalties. This asymmetry in how players respond aligns with the "reference-dependent" framing central to prospect theory.

H2: The effect of VAR interventions on penalty conversion rates varies systematically across different phases of the match.

Our findings support this hypothesis, demonstrating that the negative effect of VAR confirmation is most pronounced in early match phases and diminishes as the game progresses, although this temporal decline only reaches statistical significance on the 10 % level. This temporal pattern may help reconcile previously contradictory findings by Almeida et al. (2016) and Chiappori et al. (2002) regarding penalty success across match periods, as VAR represents a previously unexamined factor particularly affecting early-game penalties. Incorporating the temporal interaction sharpens the estimation of the main effect, underscoring the importance of temporal context in assessing the role of VAR.

Interestingly, while the negative effect weakens throughout the match, it even trends slightly positive in later phases, though not reaching statistical significance. This pattern aligns with Cotterill's (2010) suggestion that additional preparation time might benefit performance and Jordet and Hartman (2008) who find a shortened preparation time correlating with lower success rates for penalty kicks. The early-game vulnerability may reflect either heightened psychological significance of initial match events or players' gradual adaptation to pressure as competitions unfold.

Beyond these specific hypotheses, our study demonstrates that technological officiating innovations can introduce unintended psychological consequences even while enhancing decision accuracy. Our findings partially confirm those of Veldkamp and Koning (2023), who also identified a negative effect of VAR interventions on penalty conversion rates. While their study identified a general decrease in success rates from 81 % to 73 % with VAR interventions, our more differentiated analysis shows that this effect predominantly occurs with Type 1 interventions and is particularly pronounced in early match phases. This temporal dimension of the VAR effect has not been examined in previous studies. The distinct outcomes observed between Type 1 and Type 2 interventions underscore the importance of procedural design in technological implementation. Seemingly minor protocol distinctions can substantially influence performance outcomes.

For players and coaches, our findings suggest that adopting specific mental strategies to counteract early-match uncertainty during VAR reviews may prove beneficial. Training simulations that incorporate extended uncertainty periods could potentially build resilience against these disruptions, particularly for penalties occurring in early match phases when vulnerability appears highest.

Several limitations warrant acknowledgment. Our observational design cannot definitively establish causal mechanisms, and we cannot account for individual differences in pressure response or previous penalty experience. Additionally, our focus on German football raises questions about generalisability across leagues with different VAR implementation histories and penalty-taking traditions. Lastly, our dataset lacks information on the actual duration of VAR reviews, which likely varies considerably and may influence the magnitude of psychological effects. Future research incorporating precise timing data could explore this dimension. Future research could also address these limitations through experimental approaches or cross-league comparisons that might strengthen causal inferences.

7. Conclusion

This study contributes important empirical evidence regarding the psychological impact of video assistant referee (VAR) interventions on penalty kick performance in professional football. Our findings clearly indicate that penalties subject to Type 1 VAR reviews, those confirming initially awarded penalties, exhibit notably lower conversion rates compared to both Type 2 interventions and penalties awarded without VAR involvement. This effect is particularly pronounced during early match phases, diminishing as the match progresses, and underscores the significant psychological burden introduced by prolonged periods of uncertainty.

Our results suggest the necessity for football governing bodies and stakeholders to carefully consider the procedural aspects of technological officiating tools, as subtle differences in implementation can significantly influence performance outcomes. As technological officiating aids become increasingly prevalent across sports, understanding their psychological impact becomes crucial for maintaining the integrity of competition. Future research should explore cross-league comparisons and experimental methodologies to further elucidate the psychological mechanisms underlying these effects. Ultimately, balancing technological accuracy with the preservation of athlete performance integrity represents a crucial challenge as officiating technologies continue to evolve in professional sports contexts.

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