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Unfulfilled Prophecies in Sport Performance

Active Inference and the Choking Effect

Abstract: *Choking effect (choke) is the tendency of expert athletes to underperform in high-stakes situations. We propose an account of choke based on active inference — a corollary of the free energy principle in cognitive neuroscience. The active inference scheme can explain certain forms of sensorimotor skills disruption in terms of precision-modulated imbalance between sensory input and higher-level predictions. This model predicts that choke arises when the system fails to attenuate the error signal generated by proprioceptive sensory input. We aim to expand the previous formulations of this model to integrate the contribution of other causal factors, such as*

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confidence erosion, taking into account the empirical evidence emerging from the psychological research on performance disruption in sports. Our expanded model allows us to unify the two main theories of performance disruption in the sport psychology literature, i.e. the self-monitoring/execution focus theory and the distraction/ overload theory, while recognizing that the typical manifestations of choke in sport competitions are best accounted for by self-monitoring/ execution focus theory. We illustrate how active inference explains some experiential aspects of choke that are familiar to sport psychologists and practitioners: choke is a skill-level specific phenomenon; alleviated by ritual-like pre-performance routines; aggravated by personal and contextual factors such as self-confidence erosion and performance anxiety; accompanied by a drop in the attenuation of the sense of agency normally associated with high performance and flow states.

Keywords: sport skill; performance disruption; free energy principle; active inference; choking effect; proprioception; attentional focus; execution focus.

1. Introduction

Choking effect (henceforth, choke) is the tendency of experts to underperform in high-stakes situations — paradigmatically, athletes during tournaments (Beilock, 2011). Choke is just one particular form of performance disruption, i.e. the significant drop in the quality and accuracy of skilled sensorimotor action due to cognitive and motivational factors. Choke represents a concrete concern for sports practitioners and an interesting puzzle for cognitive scientists and performance psychologists, who have proposed opposing explanations of its causes and diverging intervention protocols to mitigate its effects (Cappuccio *et al.*, 2019).

In this paper, we propose an account of choke based on *active inference* — a corollary of the free energy principle (FEP) in cognitive neuroscience (Clark, 2016; Friston, 2010; Ramstead, Kirchhoff and Friston, 2019). The FEP starts from the assumption that for any living system to remain alive it must avoid crossing its terminal phase boundaries. Under the FEP, a system (or agent) can do so only by minimizing the dispersion of its sensory observations, given that it is only observations that are informationally available to an agent. Information-theoretic free energy bounds surprise (i.e. disorder) because the former can be shown to be either greater than or equal to the latter (Kirchhoff *et al.*, 2018; Parr and Friston, 2017). This means that any agent that works to minimize its free energy necessarily reduces surprise (or statistical uncertainty), where surprise is the deviation between predictions about causes of sensory input and the actual input. Minimizing free energy has also been aptly named *self-evidencing*, since the result of free energy minimizing is better evidence for an organism's predictions of the causes of its sensorium (Hohwy, 2016). Under the FEP, sensory observations are generated by hidden states in the environment (i.e. external causes of sensory outcomes), which, in turn, are causally influenced by action policies the agent pursues (i.e. infers as most likely to minimize the expected free energy associated with future sensory outcomes conditioned on action). This brings the notion of inference (or expectation) generation to the forefront, for active inference crucially implies that for any action to ensue it must be inferred as the most optimal action to pursue (Clark, 2016; Robertson and Kirchhoff, this issue).

Active inference is relevant to sport psychology because it construes skilful performance (e.g. expert sensorimotor control in sport) to consist entirely in inferring predictions that best capture the causal regularities in the (bodily or worldly) environment generating sensory input. Specifically, active inference yields sport psychology with a computational framework by which to understand the generation of bodily movement conditioned on predicting the movements themselves and their resulting sensations (Clark, 2016; Friston, 2011a). Conversely, the same active inference account allows us to model choke in terms of the system's inability to reduce the mismatch between sensory expectations and movements produced to fulfil those expectations. Over short timescales, such as involved in learning, agents become better at exploiting their actions to keep them within expected states (i.e. states with a local free energy — or prediction error — minima). Highly skilled athletes are a case in point. Yet under pressure to produce their best performance, i.e. when very precise predictions are needed to generate context-specific and perfectly fitted actions relative to the task domain, some athletes choke. Active inference provides a way to approach choke, suggesting initially that choke results from an inability to properly fit a model (prediction) to sensory (proprioceptive, exteroceptive) data.

In recent years, active inference has been used to model sensorimotor disruption in terms of precision-modulated imbalance between sensory input and predictions (Adams, Shipp and Friston, 2013; Brown *et al.*, 2013; Clark, 2016, p. 218; Limanowski, 2017). This work offers the foundational neurocognitive notions necessary to explain why choke arises when athletes are prevented from selectively disattending to their bodies during action execution and preparation. The notion we shall explore here is that choke arises given less precision assigned to sensory predictions conditioned on action, which, in turn, results in excessive self-attention (i.e. in more and more predictions required to settle on an action). In other words, in choke the agent (or better, its computational dynamics) fails to properly attune its predictions to the causes of sensations, leading to less and less precision assigned to the selection of action policies (i.e. predictions about ensuring movement). It is this apparent failure to properly calibrate proprioceptive input during movement with predictions about sensations given movement that leads to choke. In addition to addressing choke, our key proposal builds on and expands this idea, showing that an active inference approach to choke fills a theoretical gap in the sport psychology literature by offering an information-theoretical account that flexibly explains how self-monitoring, in combination with other contingencies frequently encountered in pressure-filled environments, can damage the performance of expert athletes.

This is not the only explanatory advantage offered by active inference. It also makes it possible to adjudicate between rivalling theories of choke when contextualized in the broader psychological debate on performance disruption, of which choke is just a particular case. The debate on performance disruption is dominated by two theories: (a) the self-monitoring/execution focus theory (EFT); and (b) the distraction/cognitive overload theory (DOT). EFT asserts that expert performance is systematically damaged by explicit attention to one's own body while movement is executed or prepared (Masters, 1992; Beilock and Carr, 2001; Wulf, McNevin and Shea, 2001). DOT, on the other hand, states that high performance is primarily damaged by a *lack* of attention to action execution, not the *excess* of it (Wine, 1971; Sarason, 1988; Mullen, Hardy and Oldham, 2007).

Although EFT and DOT are usually taken to offer competing accounts of choke, in principle they are not mutually exclusive explanations of performance disruption. In fact, while they cannot both be right about the causes of choke, each theory seems able to correctly describe only a specific type of performance disruption, and choke is one of the two. EFT correctly identifies the cases of performance disruption that have to do with the *misassignment* of well-honed sensorimotor routines to deliberate control (despite habitual action control not requiring explicit decision). DOT is better positioned to explain other forms of performance disruption, as it highlights that performance may be damaged via *depletion* of available cognitive resources, a problem that can affect both experts and novices, and not only in skilled sport activities. We will argue that the specific kind of performance disruption experienced by expert athletes during pressure-filled scenarios like sport tournaments is the one satisfactorily accounted for by EFT, not by DOT.

In this paper, after introducing the EFT/DOT distinction (Section 2) and illustrating the general features of the active inference approach to choke (Section 3), we aim to move the field forward by showing how active inference can unify EFT and DOT within an overarching explanatory framework of performance disruption (Section 4). This framework allows us to: account both for diverse manifestations of performance disruption in sports and for the specificity of choke among them (subsection 4.1); recognize that the cognitive mechanism that distinctively underpins choke in expert athletes is misassignment, as per EFT, not depletion, as assumed by DOT (subsection 4.2); explain how the disruptive effect of self-monitoring is modulated by individual and context specificities (subsection 4.3). Also, we discuss how active inference can capture the complex phenomenology of choke, accounting for some key features well-known to practitioners and experimenters in sports (Section 5). We conclude in Section 6.

2. Choke in Sport Psychology

Choke is the paradoxical phenomenon where expert athletes drastically underperform in situations that pressure them to produce their best performance, e.g. during tournaments (Baumeister, 1984). In the paradigmatic choke scenario, an athlete struggles to execute tasks that in normal circumstances they would have considered routine and effortless, e.g. a professional golf player that repeatedly fails a short-distance, uncomplicated putt that they normally have very high chances to complete successfully.

The disruption of the skilled sensorimotor performance of an expert can have numerous causes and manifest itself in different ways. Sport psychology is specifically concerned with the forms of performance disruption whose causes are not merely organic or physiological, but involve emotional, motivational, attentional, and cognitive factors such as distraction, fatigue, extreme arousal/drive, and panic, *inter alia*. Choke is just another variety of performance disruption imputable to psychological factors, but it is a very peculiar one in that it does not have a specific symptomatic expression or an obvious exogenous cause.[5] Peculiarly, choke seems to hit harder when the athlete is completely focused on the task at hand and is doing all that is (supposedly) required to achieve optimal results, including filtering out extraneous thoughts and worries (Gray and Allsop, 2013). This is why the substandard results due to choke are unexpected and typically experienced with a mix of disbelief and frustration (Hill and Hemmings, 2015). These negative emotions contribute to aggravate pre-existing tension and insecurity, which, in turn, accentuate the risk of choke.

To explain choke, we need to adjudicate between two leading theories of performance disruption in experimental and theoretical research: the *self-monitoring/execution focus theory* (EFT), and the *distraction/cognitive overload theory* (DOT). Both of these theories link performance disruption to the inappropriate usage of cognitive and attentional resources, but they differ in that they ground performance disruption in either an excess or a lack of attention to the task at hand, respectively (Cappuccio *et al.*, 2019).

EFT claims that skilful performance drops when the fluid motor sequences generated by well-practised, and to a large extent automated, sensorimotor routines are disrupted by obsessive self-monitoring. The assumption is that well-practised motor behaviours are faster, more fluid, and consequently more precise when executed without explicit self-monitoring, as deliberately focusing on the action execution reportedly interferes with the dynamic, smooth integration of fine-tuned and well-coordinated movements that characterize expert, automated action routines (Beilock and Gray, 2007; 2012).

DOT, in turn, states that performance disruption is caused by recurrent thoughts and distracting worries, which fill up the mind of the athlete, preventing them from correctly focusing on the task at hand: in this case, the assumption is that high performance requires high concentration, because the total amount of working memory available to an expert is limited, and has to be allocated among all the tasks simultaneously carried out (Sarason, 1988; Christensen, Sutton and McIwain, 2015).

5 This is one of the reasons to neatly distinguish between choke and 'the yips', a neurological condition characterized by patently debilitating symptoms like spasms and tremors.

These two approaches suggest opposite remedies for preventing performance disruption: EFT recommends distraction from overt execution focus; DOT recommends focus to prevent distraction (Jackson and Beilock, 2008). Nonetheless, the debate in sport psychology is polarized around EFT and DOT, and often stresses their points of contrast and conflict. These two theories are often taken as mutually exclusive models of the same specific form of performance disruption, i.e. for the cognitive mechanism responsible for the phenomenon usually referred as choke. Namely, the proponents of DOT assume that choke arises from a *depletion* problem (excessive cognitive task demands on limited cognitive resources), while the proponents of EFT maintain — against DOT — that choke is caused by a *misassignment* problem (explicit control is used for a sensorimotor routine that is better controlled by implicit processes than explicit ones). Hence, DOT assumes that skilful expertise primarily depends on the *quantity* of cognitive processing (working memory usage) done by the system to carry out the task at hand, while for EFT the problem is the *type* (deliberate or automatic processing, *cf.* Schneider and Chein, 2003).

The explanations based on depletion and misassignment support conflicting predictions about performance in dual-task conditions — e.g. when a golf player must put a ball in a golf hole while conducting a secondary cognitive task that engages working memory (Beilock *et al.*, 2002). Depletion assumes that even a perfectly well-trained action can fail if the cognitive burden of all the concurrent tasks combined is excessive, unless the secondary task is precisely about monitoring the primary one to improve its execution. Misassignment, in turn, assumes that the cognitive task can damage the concurrent expert sensorimotor performance only if the former is specifically *about* the latter, i.e. if deliberate, cognitively effortful attention is used for controlling a well-trained embodied task that, in itself, being automated, does not require attentive analysis or deliberate control to be executed properly.

A vast amount of empirical data collected by independent research groups using different experimental settings indicate that misassignment explains much better than depletion why many experts unexpectedly fail in well-trained, self-paced, closed, and typically ballistic sensorimotor tasks that involve a significant habitual component. This evidence includes the following:

1. performance of experts is damaged more by skill-focus dual-task conditions (attention to movement instructions) than split-

attention dual-task conditions (attention to external stimuli instructions), while the reverse pattern of disruption applies to novices (Beilock and Carr, 2001);

2. performance of experts does not experience the typical time/accuracy trade-off that characterizes the performance of novices (Beilock *et al*., 2008);
3. experts experience a trade-off between the quality of their sport performance and the accuracy of their skill-focused judgments about that performance because they tend to pay more attention to their own actions when they are under pressure (Gray, 2014);
4. experts display characteristic 'expertise-induced amnesia': despite showcasing better self-judgment and retrospective task analysis than novices, they have less accurate episodic memory (Beilock and Carr, 2001);
5. experts often experience an attenuated sense of agency during flow states, suggesting an inverse correlation between peak performance and perceived self-awareness (Swann *et al.*, 2012);
6. experts perceive the target of their actions with greater detail and accuracy during successful performance (for example, expert golfers report a bigger-than-real size of golf holes) which suggests a correlation between peak performance and an increased focus to the action's target (external focus) as opposed to oneself (internal/execution focus) (Gray and Cañal-Bruland, 2015);
7. expert performance is damaged by 'internal' (i.e. execution) focus (body part, component movements), not external focus (action effects, strategic intentions) (Wulf, McNevin and Shea, 2001);
8. experts can generally filter out negative thoughts better than novices, using concentration and visualization techniques, which speaks against DOT's claim that overload is the primary cause of choke in experts (MacIntyre and Moran, 2007);
9. experts who tend to choke often find relief in therapeutic approaches based on distraction (Cappuccio *et al.*, 2019); and, finally;
10. there is no obvious correlation between working memory capacity and skill level, and greater capacity correlates to better performances only in sport tasks that heavily rely on working memory (Beilock and Carr, 2005). This makes it difficult for DOT to explain why choke affects only experts, not novices.

So, while both EFT and DOT can account for at least one form of performance disruption each, experimental data on attention misassignment in sport performance clearly suggest that choke can be accounted for by EFT much better than DOT. If DOT is still very popular it is mainly because it relies on a very familiar neurocognitive model based on the traditional notion of depletion, while many psychologists are still not acquainted with the story used by EFT to explain the neurocognitive underpinnings of the misassignment problem.

EFT claims that what causes choke is explicit attention to the control of expert movements, and active inference casts this in terms of an excessive perceptual sampling of the environment (i.e. attending to bodily movements) combined with a low precision assigned to the active policies that normally elicit the proprioceptive sensations that successfully drive expert action. This idea is *prima facie* in tension with the intuition that more proprioceptive information can only help in making action control more accurate by increasing bodily self-awareness. Why would bodily self-awareness disrupt action control? Dispositional reinvestment theory answers this question by claiming that explicitly monitoring one's movements damages action execution because it defers action control to explicit rules and instructions that the expert had internalized during learning, involuntarily triggering their regression to a novice-like semi-skilled condition (Masters and Maxwell, 2008). Other qualitative accounts appeal to an alleged interference between thought and action (Dreyfus, 2005), subconscious self-sabotage (Jordet, 2010), or 'estrangement from oneself as a lived body' caused by self-consciousness (Limanowski, 2017). All of these accounts capture some important implication of the misassignment mechanism, but they do not exhaustively account for the neurocognitive and information processing mechanisms that explain EFT at the subpersonal level.

We aim to develop such an account via the active inference scheme in this paper. In the next section we will examine this scheme in detail before discussing how it situates itself in the sport psychological debate in Section 4.

3. The Active Inference Model of Choke

In this section we provide an overview of active inference under the *free energy principle* (FEP), before turning to consider choke through the lens of active inference. The FEP states that for organisms to maintain their integrity they must minimize an information-theoretic quantity known as *free energy*, given that free energy can be shown to be an upper bound on surprise. Free energy minimization is therefore also an expression of Bayesian model optimization, given that reducing surprise is equivalent to garnering evidence for a model or prediction about the bodily or extra-bodily environment. Crucially, active inference captures the idea that Bayesian model optimization need not only occur by updating internal states in light of new evidence (aka perceptual inference). Bayesian model optimization can also take place during action. Active inference provides the FEP with an embodied and enactive perspective (Ramstead, Kirchhoff and Friston, 2019), where action is cast as the process of selectively sampling expected sensory observation conditioned on embodied activity.

Active inference rests upon a generative model of sensory outcomes. A generative model is a probabilistic mapping of how some sensory outcomes might have been generated given prior beliefs about external causes, the probabilistic dependencies between external causes and sensory outcomes, and a likelihood function between external states and sensory outcomes (Parr and Friston, 2018). Generative models serve the function of enabling a system to predict sensory outcomes by inferring the causes that could have elicited its sensory observations.

In the context of generative models, active inference allows an agent to seek out the action policies or routines that yield its expected (future-oriented) sensory observations, which suggests that sensory observations depend on action. This yields active inference with a hierarchical and counterfactual dimension, as it implies inferring over counterfactual sensory outcomes given different action policies. Crucially, given 'that the generative model enables inference about hidden states based on observations, agents can also form expectations about future states [movements, states in the world, etc.]' (Schwartenbeck *et al*., 2018, p. 5).

This is especially important for our purposes, for active inference emphasizes the crucial role of action in the minimization of surprise or prediction error, where the motor system is non-trivially involved in free energy or prediction error minimization.[6] Unlike in perception,

[6] Note that we are helping ourselves to a simplification here, treating the notions of free energy minimization and prediction error minimization as (more or less) equivalent.

where prediction error signals are about exteroceptive states, action selection targets predictions and error signals in relation to *proprioception* (i.e. they are about posture and position of the body's joints and forces applied to them) (Adams, Shipp and Friston, 2013; Friston *et al.*, 2012). This captures the following distinction between *perceptual inference* and *active inference*. In perceptual inference, prior beliefs are updated in light of error signals. In active inference, the motor system suppresses error signals by performing the predicted movement (Friston, 2011b; Adams, Shipp and Friston, 2013; Brown *et al.*, 2013).[7]

Within active inference, the exploration–exploitation distinction will be especially relevant as we turn to the phenomenon of choke. This distinction speaks to goal-directed behaviour in the setting of motor control, given that motor control can be associated with finding the right balance between *exploitation* (choosing the most valuable or optimal movements given prior beliefs about the world) and *exploration* (choosing movements that promote foraging and learning about the world). The distinction between exploitation and exploration has been shown to map onto the distinction between *pragmatic* and *epistemic* actions, respectively, enabling agents to exploit specific actions to elicit certain transformative outcomes (e.g. reaching for the golf club), and to explore alternative strategies enabling better decision making (e.g. when a golf player is in the rough having to make decisions about the direction of wind, ground conditions, club selection, and so on). Hence, in exploitative (pragmatic) action, the agent adjusts their movements in accord with their current beliefs; whereas in explorative (epistemic) action, the agent is engaged in sampling sensory outcomes with high surprise or uncertainty in order to update their beliefs, and only subsequently find an optimal or close to optimal sequence of actions given the task at hand (Kirsh and Maglio, 1994). This distinction is relevant to sport psychology because pragmatic actions can be associated with *specialized* action implementation (informing task-specific skilful habitual action), while epistemic actions can be cast as *generalized* action selection strategies (in deliberate and reflective tasks), allowing for sampling of

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Nothing in our account hangs on the precise details of the relationship between free energy minimization and prediction error minimization, and we will therefore not labour on this issue any further in this paper.

7 Later in this paper we will elaborate on the notion that suppressing prediction error through performing the predicted movement involves a form of *sensory attenuation*.

alternative outcomes. Depending on the task at hand, agents will make use of either pragmatic or epistemic actions, or some mix of both action selection strategies (Chen *et al.*, 2019).

This prompts the question of how an active inference system is able to turn inference into action. The simple answer is that action is achieved by the system predicting or inferring its own motor trajectories (Clark, 2016). In action generation, active inference takes the form of making inferences about counterfactual outcomes (the trajectories of one's limbs and bodies), specified in terms of proprioceptive consequences. Hence, under active inference, movement comes about by predicting the proprioceptive states that bring such movement about. As Clark puts it: 'Such predictions are self-fulfilling prophecies. Expecting the flow of sensation that *would* result *were* you to move your body so as to keep the surfboard in that rolling sweet spot results (if you happen to be an expert surfer) in that very flow, locating the surfboard right where you want it' (*ibid.*, p. 111). Crucially, generating a high volume of precise counterfactual predictions about possible proprioceptive outcomes while reducing the flow of error signals relative to such predictions is paramount to produce accurate skilled actions and fluid bodily movement. This means that movement results from settling on the right balance between weighting sensory predictions and their error signals. As Clark puts it: 'At the limit, errors associated with the higher-level proprioceptive predictions (specifying the desired trajectory) would be accorded a very high weighting, while those associated with current proprioceptive input (specifying the current position of the limb or effector) would be low-weighted' (*ibid.*, p. 216). Differences in how error signals are weighted implies that some signals come to play a functional role on the generation of actions, while others can be confidently ignored by the system.

This is important for our purposes, since to reduce the precision of ascending information and hence initiate skilful action the system needs to reduce proprioceptive and somatosensory prediction error via sensory attenuation. Sensory attenuation is normally associated with self-generated movement, and it is necessary to produce and control intentional behaviour under active (Bayesian) inference. Sensory attenuation can be understood as the attenuation of sensory precision. A failure of sensory attenuation may lead, among other things, to false inference and beliefs about agency (e.g. illusion in schizophrenia, *cf.* Brown *et al.*, 2013).

To allow sensory attenuation in the context of high sport performance (i.e. very accurate self-paced sensorimotor tasks), the agent may need to withdraw attention from their body's occurrent state and rather focus on the predicted sensory effects of the intended end state. They need to attend the distal target or expected outcome of one's action, rather than the movements that compose that action, using an external focus rather than internal (i.e. execution) focus, as per EFT. Choke occurs, when — in the face of having to produce and select very precise action policies — the system cannot reduce prediction error given a lowering of the precision assigned to the relevant action policies. This happens when, compulsively acting as this was the best method to produce very accurate and fast movements, the agent uses execution focus to guide their action. Experienced agents often expect that attending their own movements will increase the precision of their proprioceptive predictions, as they are used to believing that deliberately supervising their body calibration could help maximize action accuracy and efficacy.[8] This expectation proves wrong in a significant number of cases.

Choke occurs in such cases because, instead of providing the system with additional information useful to correctly calibrate action, over-scrutinizing (i.e. generating more sensory samples than usually required to perform the action) is effectively the same as not being able to trust one's predictions about movement induced sensations. This brings out an interesting way to approach what happens at the experiential and computational scales. Experientially the agent is attending to her movements too much. Computationally, this kind of over-attending rests on prediction errors being precision-weighted higher than predictions about movement induced sensations, which leads to the agent having to over-sample her movements.

Due to such imbalance, the predictions generated at the higher levels, which encode the general expertise necessary to accurately shape skilful actions, are not precise enough to cancel out the errors ascending from sensory input, and moreover the sensory stream is not precise enough to update the high-level beliefs. 'Consequently, no sufficiently precise proprioceptive prediction errors are generated, and no (or abnormal) movement results' (Adams, Shipp and Friston,

8 Later (subsection 4.3) we will clarify that self-monitoring does not necessarily lead to performance disruption, but it does so when it occurs in combination with other circumstances, for example when it is performed exploratively rather than exploitatively.

2013). In other words, paying attention to one's own movement, or to their own body during the delicate process of action preparation (in which predictions about the effects of different possible action courses are generated and compared), is likely to hinder — rather than facilitate — the calibration of skilful action because explicitly attending to the sensory input generated by one's own body increases the weight of the ascending prediction errors, which contradict 'the descending predictions of the sensory consequences generated by movement. These errors have now more influence on higher-level beliefs, which are therefore adjusted to accommodate the fact that no movement is sensed' (*ibid.*).

A different way of putting this would be in terms of the distinction between exploitative and explorative actions. Expert performers are able to exploit specific action policies to elicit expected proprioceptive consequences. Through learning, the distribution of possible action policies is optimized by pruning away suboptimal policies. This suggests that, for experts, certain action policies when calculated against expected proprioceptive outcomes have a sharp probability distribution, raising the probability of very specific actions being selected given the task environment. From this perspective, choke is effectively the result of a flattening of the probability distribution over which action policies are inferred, forcing the agent to entertain multiple policies with high surprise — in other words, forcing the agent to sample alternative outcomes conflicts with their expectations given a history of performance. Choke, under active inference, can therefore be cast as suboptimal precision-modulation between predictions and error signals.

There are aspects of the active inference model of performance disruption that even its proponents have not explicitly discussed: firstly, previous accounts have described only choke, without comparing it with other (only apparently similar) types of skilful performance disruption; secondly, they appeal only to EFT, not DOT, to explain performance disruption; thirdly, the account of choke based on EFT assumes that self-monitoring and misassignment always appear together. The next section aims to examine in detail these three aspects.

4. Situating Active Inference in the Sport Psychology Debate

To link the active inference model to the sport psychology debate, we need to answer the following questions. Does the model account for the cases of performance disruption illustrated by EFT and DOT? (4.1); does it rely on the depletion or the misassignment mechanism, and how does it differentiate among them? (4.2); and does choke systematically result from self-monitoring? (4.3).

4.1. EFT vs. DOT

Active inference allows us to distinguish between choke and other forms of performance disruption, including the forms that DOT attributes to overload and distraction. Also, the model ultimately confirms that EFT can account for choke much better than DOT.

Active inference unpacks the EFT explanation of choke, i.e. the claim that over-attending one's actions as they are executed is detrimental to performance, in terms of a generative model for action that is overfitted because of the disproportionate weight attributed to the proprioceptive sensory input. An overfitted, or over-predictive, model is a model that captures 'not only the variance due to the variables of interest but also that from random error, which organisms are likely to encounter in an uncertain world' (Marewski, Gaissmaier and Gigerenzer, 2010, p. 106). Under active inference, the model is overfitted when it extracts from the proprioceptive sensory signal more parameters than could be justified by the data because of its inability to properly filter out all the irrelevant information (noise). This increases the discrepancies between the predicted and the perceived trend in proprioceptive sensory data to the point that the system becomes unable to plan the action that would reduce such discrepancies, resulting in no or suboptimal action (or in inflexible, stereotyped behaviour, as in autistic subjects, *cf.* Idei *et al.*, 2018).

Conversely, a statistical model is underfitted if it cannot accurately capture the underlying trend of the data because it ignores some of the relevant input, essentially treating it as noise. Underfitting can account for some of the cases of performance disruption considered by DOT, namely when poor self-attention reduces the ability to extract sufficient parameters from the proprioceptive sensory signal, which results in no or suboptimal action. In so far as poor attention is often caused by distraction and cognitive overload, also DOT can be accommodated in the active inference scheme, but in a role that has nothing to do with choke. Thus, cognitive overload and distraction may prevent the system from making proper use of the sensory input signal, whose precision is insufficient to provide a guide for action. This can happen when the circumstances are unexpectedly complex, challenging, and unfamiliar: for example, in scenarios characterized by high uncertainty due to the insufficiency or irrelevance of the available prior knowledge. Navigating such scenarios require computationally demanding decisional processes that are not necessarily eased by sensorimotor expertise. In the tasks in which analysis of proprioceptive sensory data is crucial to be successful, thus significant demands on working memory may lead to troubled or substandard performance.

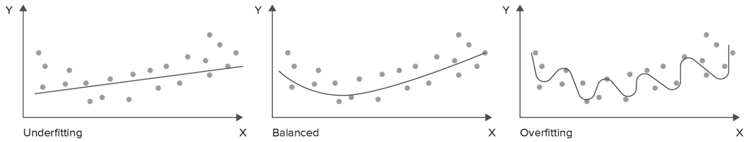

Figure 1. In the context of linear regression, a model generated by machine learning is considered underfitted, robust, or overfitted, depending on whether the number of parameters extracted from data is too small, adequate, or too big.

However, as argued in Section 2, this is not what normally happens to athletes suffering from choke during competitions. The frustration experienced by a choking athlete is caused by their temporary inability to produce routine, habitualized actions in familiar sensorimotor contexts that are not taxing for working memory. The kind of underperformance based on EFT can only be explained by unattenuated proprioceptive input and overfitting, which is what typically happens to expert athletes when task pressure and performance anxiety compel them to obsessively focus on the details of the motor components of the action they are about to execute.

EFT and DOT identify different cases of performance disruption; they also offer different cognitive mechanisms underpinning action control. This is important to answer the second question; namely, does choke arise given depletion or misassignment mechanisms, and can active inference help us differentiate among them?

4.2. Misassignment vs. depletion

Active inference supports an explanation of choke in terms of misassignment, rather than resulting from issues around depletion. Performance disruption characterized as choke is not caused by an overflow of the available cognitive capacity caused by too demanding computational tasks, but by the improper precision modulation of sensory signals. Interestingly, when the cause of substandard performance is self-monitoring, distraction can be an effective intervention to improve performance, while reducing the cognitive load in order to free up working memory is not necessarily beneficial (Buszard, Masters and Farrow, 2017). Thus, if proprioception plays a role in paralysing the system this is not because ascending signals carry too much information *per se*, but because top-down predictions do not capture all the counterfactual trajectories of bodily movement implied by such information. Choke is not caused by the depletion of working memory, as claimed by DOT, because the problem is not the *quantity* of information *per se*, but the *type* of sensory information (proprioceptive) utilized to calibrate action control. Crucially, and as we have been arguing, active inference not only casts choke in terms of first-order predictions about sensorimotor contingencies; in addition, it adds the notion that choke occurs given the failure to lower the precision assigned to prediction error.

The active inference model of choke challenges a centralized view on expert performance and skilful action. This view presupposes the notion — borrowed from traditional computer science — that cognitive performance directly correlates to working memory availability: performance decreases when the system is burdened with heavy computational tasks and increases when action execution is attentively monitored, as self-observation provides proprioceptive information relevant to online control. Also, this view assumes that skilful embodied action control, not differently from logico-symbolic and propositional tasks, depends on the system's computational power (i.e. the data processing rate). The active inference model challenges these assumptions because it offers an alternative explanation of how performance disruption can be caused by mechanisms different from computational overload. This suggests that expert skilful control of sensorimotor action has less to do with brute computational power and much more with online sensorimotor attunement, coupling agents, and environment dynamics.

The aforementioned experimental results on performance in dual-task conditions suggest that choke occurs when misassignment (not depletion) ensues. This confirms the hypothesis of an at least partial functional segregation of skilful action control from the processes consuming working memory, which corroborates EFT and challenges DOT, proving that the problem behind choke is not the quantity of cognitive resources used for a sport task, but the type.

4.3. Choke's specificity

The active inference model imputes choke to self-monitoring because self-monitoring (action control guided by internal or execution focus) prevents the required attenuation of proprioceptive and somatosensory input. We need to clarify how deep and systematic the relation between self-monitoring and performance disruption really is. We have already remarked that EFT is better equipped to explain choke than rival theories, although not all forms of performance disruption are caused by self-monitoring. Now we must remark that EFT is on the right track even though not all instances of self-monitoring result in performance disruption. In fact, the cases of athletes chronically prone to choke are arguably less common than the athletes occasionally indulging in self-monitoring to guide their actions. In laboratorial settings, the negative impact of self-monitoring on expert performance is statistically significant but not as debilitating as choke in real-life professional competitions (Christensen, Sutton and McIlwain, 2015). On the sporting field, athletes are often tempted to monitor their own posture and movement to guide their performance, and this does not always provoke catastrophic task disruption. Some sport tasks (batting in cricket, swimming) and artistic performance (classical ballet) rely explicitly on self-monitoring to be carried out successfully (Sutton, 2007; Montero, 2016).

This does not mean that execution focus cannot produce chronic (long-term and severe) instances of choke, but that its disruptive potential is unleashed only in particular circumstances and in specific individuals. The disruptive impact of self-monitoring on sensorimotor control is modulated by multiple person-level variables that, combined with self-monitoring or triggered by it, cause severe performance disruption. These variables impact on expert athletes as they prepare to act with the intent to produce the best possible sensorimotor outcomes. What are these variables, and how should the active inference model be expanded to accommodate them?

To answer this question we need to distinguish between the constitutive elements of active inference leading to performance disruption and the intervening variables that aggravate it. The most detrimental effects of choke are generated by the compulsive iteration of a cognitive-behavioural loop in which imprecise predictions and excessive proprioceptive input reinforce one another. The *constitutive elements* of this loop are subpersonal mechanisms involved in free energy (or prediction error) minimization. The *intervening factors* are personal-level dynamics that may or may not intervene to aggravate the subpersonal dynamics: they are contingent upon individual idiosyncrasies related to psychological background, training methods, context, and so on. Without these factors, the consequences generated by self-monitoring/execution focus may not be too severe for the athlete's performance. The combination of constitutive elements and intervening factors explains why choke is determined by both cognitive mechanisms underlying human action control and peculiar circumstances that depend on the psychological or attitudinal specificities of the performer or the context of the performance.

First, consider the five constitutive elements (subpersonal mechanisms) of choke:

i) The *heavy pressure* that producing the best possible outcomes characterizes. This is not an emotional characterization, but an initial task-constraint that identifies specific policies to regulate sensorimotor control in accord with the cognitive demands implied by commitment to excellence.

ii) *Self-monitoring/execution focus* is applied during the movement preparation/calibration stage. It results in an increased bandwidth and sampling rate of the proprioceptive signal and an even higher weighting of this input in the precision-calibration system.

iii) The system, requested to process an increasing amount of *non-attenuated irrelevant proprioceptive prediction error*, is overfitted as it extracts from data more parameters than would ever be needed or justified from data.

iv) The overall level of systemic *surprise (disorder, noise) increases* due to the high number of sensory prediction errors. As a consequence, the attempts to calibrate action fail, and spurred movements or no movements ensue.

v) The system recalibrates to account for the lack of success of the latest inferences produced by the system. The *weight assigned to prior beliefs is weakened* to reflect the system's decreasing trust in its own predictions in consideration of its failed attempts to skilfully regulate action. Precision weighting of the following descending prediction will decrease accordingly.

Then, consider the following four intervening factors (person-level individual and contextual specificities):

a) *Reinvestment tendencies* intervene, reinforcing the causal link that connect i and ii. This is the individual predisposition to analytically control action execution, decomposing movement into its basic steps on the basis of rules and instructions, like a novice. Reinvestment has to do with the athlete's background, as it is more likely to occur to the athletes who were trained with explicit instructions and rules.
b) *Explorative approach* applied to proprioception, intervening between ii and iii. This factor describes how the sensory information gathered through self-monitoring/execution focus is used to fulfil an epistemic function rather than a pragmatic one (see later).
c) *Low self-efficacy* intervenes primarily between iv and v, modulating how the system's priors are updated on the basis of failure. This is determined by the lack of confidence in one's abilities or chances of success, which may depend on emotional or motivational fragility, or inaccurate self-evaluation. It undermines the validity of the predictions about one's success.
d) *Performance anxiety* intervenes primarily between v and i to modulate the pressure related to the situation. This emotional/motivational factor accounts for recurrent worries of failure and the importance individually attributed to the competition. Like low self-efficacy, it is modulated by negative emotions and depends on personality.

When combined, these dynamics generate an iterative process that, reinforcing itself through time, eventually leads to the meltdown of the prediction–action generation system. Schematically:

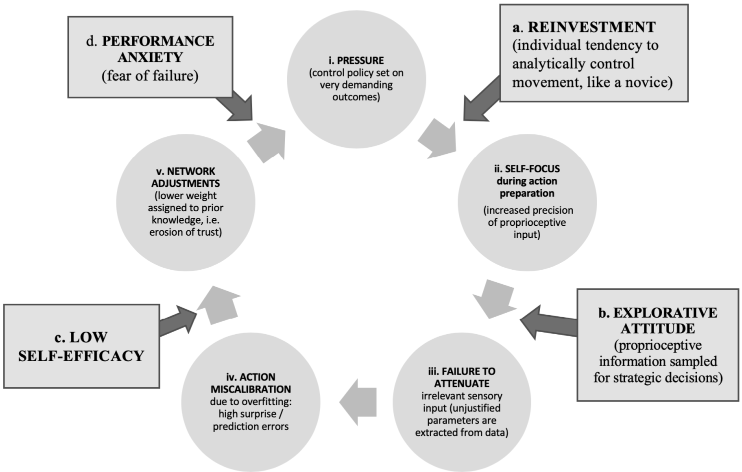

Figure 2. The circular process that iteratively leads to increasing precision-weighting miscalibration involves five structural components as part of the active inference model and four intervening factors related to psychological or contextual circumstances.

The exploitation/exploration distinction, previously introduced, needs to be further discussed to characterize factor b (explorative approach). Normally, well-trained skilled actions involve an automated component, and allow for better performances when action is based on habitual, pre-reflective embodied expertise. On the contrary, inexpert action, or skilled action in problematic and uncertain conditions, produces better performance when it is controlled by deliberate attention. The difference is that expert action in familiar scenarios has fewer degrees of freedom, as it tends to approximate an already familiar optimal model, while inexpert or uncertain action requires more degrees of freedom and more complex decisions to infer the best model. That is why expert action is successful only when accompanied by an exploitation policy, while the exploration policy facilitates inexpert or uncertain action. Sampling the perceptual environment to collect proprioceptive sensory information relevant to action execution is not detrimental *per se*, but it is detrimental when expert actions that should rely on an exploitative engagement with the environment are instead guided by an explorative approach. Exploration is key when action requires explicit decisions and strategic planning, but it is counterproductive when the policies governing an habitual behaviour are already confidently defined by expertise.

The misassignment problem associated with EFT occurs when the system samples the perceptual environment for the wrong purpose, as this causes an unnecessary inflation of the ascending proprioceptive prediction errors that, in turn, hinders the efficacious usage of the embodied expertise embedded in automatic sensorimotor routines. Choke occurs when an action that is supposed to be controlled by the exploitative policy (as it is well-trained and habitual) is rather assigned to an explorative policy, with the agent exploring its own body (sampling proprioceptive information) as if this could help improve movement calibration.

Choke is governed by an incremental, compulsive dynamic. Its disruptive trajectory is determined by the fact that, despite the high uncertainty scenario, the system is still coerced to produce optimal performances by the commitment to excellence that characterizes competitive sports. The context itself instils perfectionism in the athlete while preventing them from withdrawing from the task, despite the increasing levels of perceived risk and frustration. Prediction error peaks when the error tolerance is so low that fulfilling one's expectations is beyond their control capability. Increasing levels of surprise reinforce the urge to scrutinize even more closely their own body posture (joint angles, arm and leg positions, etc.) with higher-rate sampling. Self-observation, in turn, generates greater expectations to produce even more precise and detailed predictions about one's own actions. Action control meltdown occurs when the system eventually loses any capability to fulfil expectations that were hugely inflated despite trust in its own predictive ability dramatically decreasing.

Can this spiral be broken? Two theoretical options are in principle available to reduce the effects of prediction error and block the choke loop: (a) forcefully inducing proprioceptive sensory attenuation; or (b) artificially inflating confidence in the descending predictions (manipulating how precision is perceived/assessed). Both come with risks. Sensory attenuation can be forced by external focus or distractors (e.g. dual-task conditions) that compete with self-monitoring and decrease the bandwidth of proprioceptive information processed online. This has the effect of reducing the sensorial grain and sampling rate of haptic and visual inspections that target joint position, muscular tension, nociceptive signals, etc. Confidence inflation can be induced artificially (neuro-stimulation techniques, drugs) but it can be accompanied by behavioural rigidity (reduced adaptivity to changing contexts) or perceptual illusions (Brown *et al.*, 2013; Clark, 2016, p. 219).

To sum up, choke is control paralysis generated by frustrated perfectionism coupled with incremental erosion of trust in one's expert sensorimotor predictions. The causal dynamics underlying performance disruption are neither simply emotional (anxiety) nor merely attentional (execution focus), but a combination of the two, in addition to a wrong approach to the task (explorative rather than exploitative): as the gap between anticipated and ideal circumstances increases, the expert athlete forces themselves to generate prophecies that cannot be fulfilled just because they are too accurate and demanding.

5. Accounting for Choke's Phenomenology

The active inference model of choke must be further articulated and enriched to account for the complex phenomenology of performance disruption as it is experienced by athletes. To update the active inference scheme on the basis of the experiential reports on choke, we will address the following three aspects: choke is a skill-level specific phenomenon (5.1); choke is alleviated by self-regulatory behaviours and exacerbated by negative beliefs about oneself (5.2); and choke is characterized by the suspension of two phenomena that typically accompany peak performance in experts: expertise-induced amnesia and sense of agency suppression (5.3).

5.1. Experts vs. novices

We have already mentioned that EFT, unlike DOT, construes choke as a phenomenon that affects only experts, not novices. Active inference allows us to link this notion with the idea that skill level in sport correlates to anticipatory abilities. The predictive abilities of expert athletes are more far-reaching and fine-grained than those of novices because their learning history enables them to identify, anticipate, and respond to familiar scenarios. Skilled rugby players, for example, can anticipate seemingly random ball-bounce more accurately than less-skilled counterparts, and skilled performers are able to utilize postural cues from the kicker to predict bounce outcome (Runswick, Green and North, 2019). Expert basketball players are capable of predicting the outcome of a free-throw, of which they observed only the initial movements, faster and more accurately than novices (Aglioti *et al.*, 2008). Motor circuits of expert athletes are selectively recruited to simulate the goal-directed actions observed in others, with activation patterns congruent to the performative expertise of the observer, testifying that motoric familiarity facilitates the prediction of sensorimotor outcomes (Calvo-Merino *et al.*, 2006).

Anticipatory abilities are crucial to dynamically calibrate skilful action in fast changing environments. Eye tracking studies have documented that the attentional focus of expert table tennis players anticipates the trajectory of the ball during rapid exchanges, rather than fixating on the ball, and that the reach of such anticipation correlates to the player's skill level (Koedijker and Mann, 2015). The predictive expertise of skilled athletes shows in what Christensen and Bicknell (2019) call 'anticipatory control': expert players efficiently scan the environment to identify opportunities for action and viable adaptive strategies and, moreover, they do so dynamically and predictively, anticipating imminent changes in the landscape of opportunities for action, estimating the effects of their own actions in such landscapes, and predicting counterfactual sensory outcomes based on dependencies between sensory and motor dynamics. This allows them to regulate their conduct in a dynamic landscape of affordances, adapting not only to immediate fluctuations but also future-oriented ones.

Active inference conceptualizes the anticipatory control of expert athletes as the ability to competently navigate their niche to reduce surprise. This ability comes with a potential risk: with a heightened sense of anticipatory control inevitably come stronger expectations about the effects of one's own actions, which, in turn, require more effort to correct the selection of policies in adverse and unfamiliar circumstances.

Expertise requires trust in one's own well-trained motor habits, as expert performance largely depends on automated skilful routines that do not involve attentive supervision or explicit decision. However, confidence breakdown is both possible and likely to happen when pressure-filled environments are specifically designed to test one's ability while implicitly demanding the maximum cognitive and physical effort to achieve optimal results. When the tension reaches its peak, the dynamic integration of affordance perception and outcome prediction that is the root of anticipatory control risks collapsing.

Performance disruption due to tool change is an interesting example of how anticipatory control can collapse. It is well documented that several top golf players have suffered serious difficulties in their professional careers after having changed their equipment due to contractual obligations with a new technical sponsor (Dudurich, 2014): e.g. Curtis Strange in 1989 (switching to Maruman), Nick Price in

1995 (Atrigon), Lee Janzen in 1993 (Ben Hogan), Corey Pavin in 1995 (PRGR), and in David Duval in 2001 (Nike). As the same equipment was used successfully by other top players, we can infer that performance disruption depends not only on objective changes in the environment, but also on the subjective unreadiness to adjust to those changes. Flexibility to tool change may vary significantly and arguably correlates to skill-level, as novices do not seem to experience the same decline in performance when shifting golf equipment.

Professional players tend to develop an intimate familiarity with their favourite pieces of equipment, consequently may feel more the tension between expectations, based on previous experience, and actual tool use. Expert golf players produce much more detailed reports about the qualities of their familiar tools than novices, which indicates that experts perceive very precisely whether their tool-use experience is comfortable and confident or not (Roberts *et al*., 2001).[9] Behavioural rigidity reflects the expert athlete's difficulty to update the expectations formed during skill development. Also, as highlighted by reinvestment theory, it largely depends on the training methods used during the earlier stages of their career (Masters and Maxwell, 2008). The fact that sensitivity to equipment-change correlates to skill level confirms the intuition that sport expertise correlates both to better predictive/anticipatory abilities and to a greater fragility due to possible miscalibration and unbalances.

5.2. Pre-performance rituals

Another interesting aspect of the phenomenology of choke is the ritual-like routines that professional athletes often repeat before performance to avert performance disruption. Apotropaic beliefs are often associated to these rituals. Such superstitious beliefs can affect performance, as evidenced by a study showing that participants performed better on a golf putting task when using a ball that was said to be 'lucky' (Schippers and Van Lange, 2006). Pre-performance routines generally are more useful to the athletes who believe that the ritual is to bring luck (Damisch, Stoberock and Mussweiler, 2010). In turn, it is well-known that recurrent thoughts of failure and feelings of

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9 These qualitative reports were assessed along 10 dimensions: feel from impact; impact sound; shaft feel; club weight; club control; feel of club position during swing; grip; ball flight; club appearance; golfer's psychology, which includes associations to experiences unrelated to sport performance, for example superstitious associations.

persecution, like those entertained by superstitious people who believe themselves to be victim of a bad luck, have a negative effect on performance. The relationship between negative thoughts and performance disruption is easily explained by DOT in terms of a self-fulfilling prophecy: fear of performing poorly generates recurrent thoughts and worries that deplete the athlete's cognitive resources, causing them to actually perform poorly. But why would the belief in one's own *good* luck *increase* the actual chances of success, given that higher self-confidence cannot increase the maximum amount of available working memory? Without appealing to magic or DOT, active inference can explain why pre-performance rituals improve performance, and why this effect can be even stronger when superstitious beliefs are attached to them.

Pre-performance routines that professional athletes repeat before important challenges represent a method to reduce the perceived randomness of these events, internalizing the feeling that the world is well ordered and predictable. Pre-performance routines cannot bring about the desired outcomes, but can generate very familiar, easily replicable action patterns, whose sensory effects are well-known and expected by the expert athlete. Routine behaviour has a tranquilizing effect, as it defuses the spiral of anxiety and disappointment that typically troubles the performance of people who lack confidence in the own ability. How does it work?

As illustrated by our choke schema, loss of confidence (c) plays a role in the loop that leads to catastrophic performance disruption. Such loss erodes the system's capability to trust its own high-level predictions. Pre-performance rituals help the athletes prevent such loss of confidence by reducing surprise (iv).

By performing ritualized actions whose sensorimotor consequences are very easily predicted, athletes reduce the mismatch between predicted and perceived experience, reinforcing the system's trust in its own anticipatory abilities. A similar effect is achieved by fidgeting, an unintentional, self-regulatory behaviour that, while generated with no apparent reason, contributes to reduce the surprise associated with perceived randomness and uncertainty (Perrykkad and Hohwy, 2020).

Pre-performance rituals and fidgeting behaviour use only sensorimotor dynamics and work independently of any superstition belief — for example the belief that two causally unrelated events can affect one another at a distance. Beliefs in luck imply the perception that desirable events occur more often than non-desirable ones. Such beliefs reinforce trust in one's own predictive abilities by supporting the conjecture that hidden regularities are behind the occurrence of apparently random events. Bleak and Frederick (1998) have shown that those who believe less in chance are more likely to engage in superstitious behaviours because they have more trust in their own abilities to predict the transformative effects of such behaviours. Like pre-performance routines, also superstitious beliefs can help the system prevent the deterioration of trust in its priors in the face of disruptive events that threaten self-confidence.

5.3. Attenuated sense of agency during 'flow'

Expert athletes often report the feeling of being passively conducted when they perform skilfully. Various modalities of attenuation of self-generated sensory signals can be observed during movement (Blakemore, Wolpert and Frith, 1998; Brown, Friston and Bestmann, 2011) and movement preparation. Skilful sport performance based on automated motor routines has its own pre-reflective 'auto-pilot' modality, often associated with a state of deep absorption called 'flow'. Swann *et al.* (2012) have documented the tendency of expert athletes to describe their role in flow as a passive one, their action control being accounted for in terms of 'letting it happen' rather than 'making it happen'. In a flow state the friction between agent and world seemingly disappears (Cappuccio, 2017). Similar statements, emphasizing passivity over agency in the generation of quick, precise, skilful action are common among expert athletes (e.g. Bruce Lee's famous claim: 'I do no hit. It [my fist] hits by itself'). The athlete witnesses flow condition as a smooth and uninterrupted flux of continuously changing sensorimotor contingencies to which their movements automatically attune.

According to forward model theories, the attenuated sense of agency is an effect of optimal execution, which comes with the complete fulfilment of sensorimotor expectations as action flawlessly approximates its expected end state (Wolpert, Ghahramani and Jordan, 1995; Kawato, 1999). The experience of performing a voluntary action is made possible by the mismatch between predicted and perceived sensory effects as action is generated, therefore a nearly perfect cancellation of prediction error diminishes the subjective feeling of performing voluntarily (Tani, 2017, pp. 235–7). However, according to active inference, the extreme attenuation of proprioceptive sensory input does not only accompany skilled performance, it also enables it: sensory attenuation is instrumental to sustain action prediction minimizing the overwhelming weight of the errors generated by the robust proprioceptive feedback that result from expert movements. As Limanowski (2017) clarifies: 'the "experiential absence" of the body is necessary for action in the world… attention directed towards the objective body is detrimental to skillful action, i.e. automatized movement controlled by strongly predicted sensory consequences'.

Therefore, sensory attenuation is not only an epiphenomenon of the forward models that 'predict and thus cancel out the sensory consequences of one's movements based on the body's current state and corollary discharge' (Blakemore, Wolpert and Frith, 1998; *cf*. Friston, Thornton and Clark, 2012, for a more detailed comparison of these accounts): sensory attenuation is also a necessary condition to bring about the needed 'dis-attention away from sensory input, which would otherwise bias perceptual inference and potentially preclude movement' (Limanowski, 2017). Arguably, choke disrupts skilful performance by making this condition impossible to achieve.

6. Conclusion

In reviewing the active inference model of choke we have discussed its position within the current psychological debate on performance disruption. In active inference terms, choke arises from imprecise precision-modulation relative to predictions and error signals. At the computational level, the cause of this imprecision can be described as an insufficient attenuation of proprioceptive sensory signals which prevents the system from inferring the policies required to predict proprioceptive input to optimize performance. The problem arises because the execution of automated action routines is inappropriately assigned to deliberate, attentive control, not because of the depletion of available cognitive resources.

At the behavioural level, the phenomenon of choke experienced by expert athletes is caused by execution focus; that is, excessive attention to the component movements of well-trained sensorimotor action routines during their execution. The explanation of choke based on self-monitoring/execution focus is best captured by EFT. Other kinds of performance disruption are efficaciously accounted for by DOT. Here we have argued that EFT and DOT can both be subsumed under active inference. Moreover, in our expanded model of the causal underpinnings of choke we have identified five structural components (pressure; volume of proprioceptive input; overfitting; sensory prediction error; trust) that are iteratively reinforced as the processes underlying choke worsen. We distinguish these components from four intervening variables (reinvestment; explorative approach; self-efficacy; anxiety) that may make the effects of choke more or less severe, modulating the underlying cognitive mechanisms. Execution focus becomes particularly detrimental to automated action when self-monitoring is conducted exploratively (to make a decision about the movement to be performed), rather than exploitatively (to calibrate a familiar movement).

We have also examined how active inference accounts for certain experiential aspects of choke that are familiar to scholars and practitioners. Choke is a skill-level specific phenomenon because the risk of misassigning action control arises only when sensorimotor routines are already automated through expertise. This is when the predictive abilities become more sophisticated but also potentially fragile and more prone to overfitting, as demonstrated by expert athletes negatively affected by tool change. Also, choke is attenuated by ritual-like pre-performance routines that have a self-regulatory function and preserve trust in one's own predictive abilities, shielding skilful action control from the disturbing effects of wrong precision modulation. Last but not least, we have emphasized that the attenuation of the sense of agency is an effect associated with peak performance, which explains why selectively disattending one's own body is key to prevent choke in expert sport action.

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