Links Between Attention, Performance Pressure, and Movement in Skilled Motor Action

Rob Gray

Current Directions in Psychological Science 2011 20: 301
DOI: 10.1177/0963721411416572

Association for Psychological Science

Current Directions in Psychological Science
20(5) 301–306

DOI: 10.1177/0963721411416572
http://cdps.sagepub.com
SAGE

Links Between Attention, Performance Pressure, and Movement in Skilled Motor Action

Rob Gray
School of Sport and Exercise Sciences, University of Birmingham

Abstract

The attentional focus adopted during the execution of a skilled motor action can have a profound effect on performance outcomes. Furthermore, it has been proposed that an "inward" shift in the focus of attention may be one of the primary causes of "choking under pressure." But how does attention have its effect on performance? In particular, how does changing one's focus of attention change movement during skill execution? Here, I highlight recent research reporting four different types of movement effects that have been linked to attention: movement variability, multi-joint coordination, movement economy, and motor-control strategy. Understanding the effects of attention and pressure at the level of kinematics/muscle activity is crucial for developing a comprehensive theoretical account of skilled motor action. It is also of great practical value as it identifies specific execution errors that can be addressed in practice.

Keywords

attention, action, kinematics, pressure

Introduction

What should an athlete focus their attention on during a game or performance? Should they focus on the movements involved in skill execution—for instance, a baseball batter paying attention to the speed of his or her bat movement or a golfer focusing on the angle of the putter head? Or should an athlete focus on something in the outside environment, such as a voice in the crowd or the locations of other players on a field? Previous research has shown that what an athlete focuses attention on during skill execution can have dramatic effects on performance, with the nature of the effect depending on skill level (Wulf & Prinz, 2001).

A common methodology used to study the role of attention in sports performance involves having an athlete perform a secondary task and a sports skill simultaneously. The secondary tasks can be designed to either direct attention toward movement execution (e.g., making a judgment about the speed of a bat or club) or away from it (e.g., making a judgment about irrelevant auditory stimuli). Experiments using this approach (e.g., Gray, 2004) have shown that for experts, focusing attention on movement execution leads to worse performance outcomes (e.g., fewer hits or successful putts) while, for less skilled performers, directing attention away from skill execution degrades performance.

There is also evidence that changes in the attentional focus may be one of the primary causes of "choking under pressure" (e.g., missing a short putt to win a golf tournament). It has been proposed that high-pressure situations prompt skilled performers to shift their attention inward so that the focus is on movement execution—the constrained action hypothesis proposed by Wulf and colleagues (reviewed in Wulf & Prinz, 2001) and the reinvestment theory proposed by Masters (1992).[1] This inward attentional shift is thought to harm performance because actions that were formerly controlled by highly efficient and automatic motor programs (i.e., motor memory) are now controlled by explicit (conscious) attentional processes, which are known to be slow and error prone. In support of these theories, a performer's knowledge about his or her movement execution (when asked to make a judgment after the movement is completed) is significantly more accurate under pressure conditions (Gray, 2004), indicating that pressure induces an inward shift in attention similar to that produced by the skill-focused secondary tasks described above.

How then does attention have its effect on performance outcomes? In particular, how does changing one's focus of attention change movement during skill execution? Previous

Corresponding Author:
Rob Gray, School of Sport and Exercise Sciences, University of Birmingham, B15 2TT, UK
E-mail: r.gray.2@bham.ac.uk

research in this area has primarily focused on the effects of attention and/or pressure on performance outcomes. While performance effects are obviously the most immediate concern of an athlete or coach, movement effects may provide a more reliable and direct index. Anyone who has participated regularly in sports knows that good execution does not always lead to a successful outcome (and poor execution does not always lead to failure). Many additional variables (e.g., the reactions of opponents and environmental conditions) determine whether the execution of a sports skill will be successful. Therefore, measurement of movement effects (which are more directly influenced by attention than performance effects are) is key to developing a theoretical account of skilled motor action. It is also of practical importance. Identifying problems at the level of movement execution will improve the ability of a coach to help an athlete remedy performance failures. One can only get so far by instructing a performer to "stop trying too hard" when faced with a pressure situation.

It is only recently that researchers have both explicitly manipulated performers' attentional focus (via instruction, secondary tasks, or pressure) and measured the impact on the quality of movement. This article is a review of the early research on this topic, with a focus on four types of movement effects that have been observed: changes in movement variability, changes in multi-joint coordination, changes in movement economy, and changes in motor-control strategy.

Changes in Movement Variability

One of the primary changes in movement that one might expect to observe as a function of shifts in the focus of attention is changes in the consistency of movements produced during execution of a skill. A characteristic of the automatic, proceduralized processes thought to be involved in expert-level performance is the ability to produce movements with very low variability from trial to trial. When a performer shifts control from encapsulated and automatic procedures to step-by-step cognitive control, an increase in movement variability should occur.

I (Gray, 2004) measured the batting kinematics of skilled baseball players performing a simulated hitting task under baseline and pressure conditions (in which there were monetary incentives and social pressures to perform well). Relative to baseline performance, baseball players had fewer hits under pressure. In terms of batting kinematics (shown in Fig. 1), batters also exhibited an increased amount of variability in the timing of the different stages of their swing under pressure as compared to baseline conditions.

Why might kinematic variability increase under performance stress? I (Gray, 2004) also found that skilled batters were better able to monitor the direction their bat was moving under pressure as compared to in baseline conditions—suggesting they were attending more to the step-by-step components of execution under high-pressure as compared to low-pressure conditions. If increased attention to well-learned execution opens up the opportunity to fine-tune and adjust the execution of one's skill in a way one might not normally do, this could lead to increased kinematic variability.

Cooke, Kavussanu, McIntyre, and Ring (2010) recently reported a similar finding in a study using novice golfers. Under pressure conditions, there was an increase in the lateral acceleration of the putter head during the downward movement of the putter, which leads to an associated increase in the variability of the putter face angle at the point of contact.

Changes in Multi-Joint Coordination

Another movement effect that has been found to be related to attention is the coordination between joints during complex movements. When we first learn to perform a complex motor task like throwing a ball, there are innumerable possible ways the action could be coordinated, because each joint involved (e.g., the wrist, elbow, shoulder, etc.) has multiple degrees of freedom (*df*). As a solution to this *df* problem, Bernstein (1967) suggested that novice performers may "freeze" the *df* by keeping some joints rigidly locked in place and/or by tightly coupling the movements of different joints. With practice, performers will begin to "unfreeze" the rigid couplings between parts of the body to allow for more flexible movement control. Bernstein further proposed that under conditions of high stress, expert performers may revert to the novice freezing strategy in order to reduce the complexity of the task.

Recently, evidence has been provided to support Bernstein's account of the biomechanical changes associated with performance stress. Pijpers, Oudejans, Holsheimer, and Bakker (2003) investigated the effects of anxiety on the movement behavior of novice rock climbers. Anxiety was manipulated by having participants climb at two different heights on an indoor climbing wall. Consistent with a freezing *df* theory, when climbing high on the wall, participants exhibited movements that were more rigid and less fluent than they did when climbing at the low level on the wall.

Related results have also been found in experiments in which the performer's focus of attention is altered via instruction. Lohse, Sherwood, and Healy (2010) used a dart-throwing task and measured the variability of the shoulder and elbow joint angles. Participants encouraged to focus their attention on skill execution (i.e., the foci that is adopted by many performers under pressure) showed significantly lower joint angle variability than did participants who were encouraged to focus their attention externally (i.e., the dart board). Throwing accuracy was also significantly greater in the external-focus condition.

On the surface, these findings on multi-joint coordination, in which movements become more rigid and less variable when attention is self-focused, seem to contradict the findings described earlier that show increased movement variability. However, Beilock and Gray (2007) have argued that both of these effects represent a temporary regression to a lower skill level (associated with an earlier stage of skill acquisition)

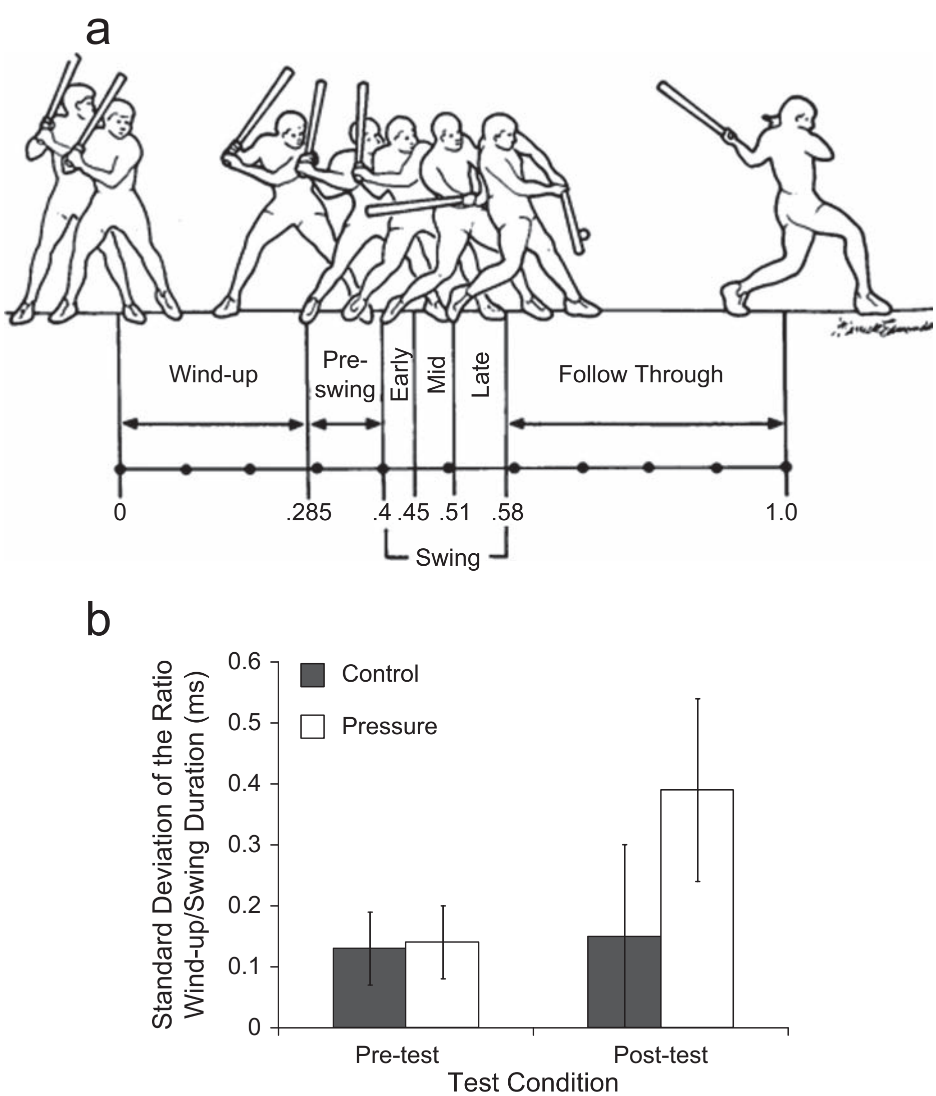

Fig 1. Biomechanical stages of a baseball swing (a) and standard deviation of the "wind-up"/"swing" ratio for the pressure and control groups (b). Panel a reprinted from "Baseball batting: An electromyographic study," by B. Shaffer, F. W. Jobe, M. Pink, and J. Perry, 1993, *Clinical Orthopaedics and Related Research, 292*, 285–293. Copyright 1993 by The Association of Bone and Joint Surgery. Reprinted with permission. Panel b reprinted from Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking and slumps. *Journal of Experimental Psychology: Applied, 10*, 42–54. Reprinted with permission.

brought on by an increase in explicit monitoring of the motor action. Whether increased or decreased movement variability is observed will depend on what aspect of the movement is being measured and whether the variability in movement is functional. In baseball batting, it has been shown that a high degree of variability in timing between the different stages of a baseball swing hurts performance by interrupting the kinetic link (Gray, 2002), and indeed it is a characteristic of novice performance. Similarly, in Cooke et al.'s (2010) study, a high degree of variability in the putter-head angle at contact leads to performance errors (i.e., "pushing" and "pulling" putts). Conversely, for other actions, movement variability can be functional, as it serves to preserve the movement outcome in response to variations in the initiation and/or early stages of a skill. For example, long jumpers free to flexibly vary the length of the final few strides of their run-ups (resulting in high variability across trials) can successfully hit a take-off board despite any variations in the initial part of the action (Lee, Lishman, & Thompson, 1982).

Changes in Movement Economy

The effect of attention on movement has also been measured using electromyography (EMG). Zachary, Wulf, Mercer, and Bezodis (2005) measured EMG activity during the performance of basketball free throws. When participants adopted

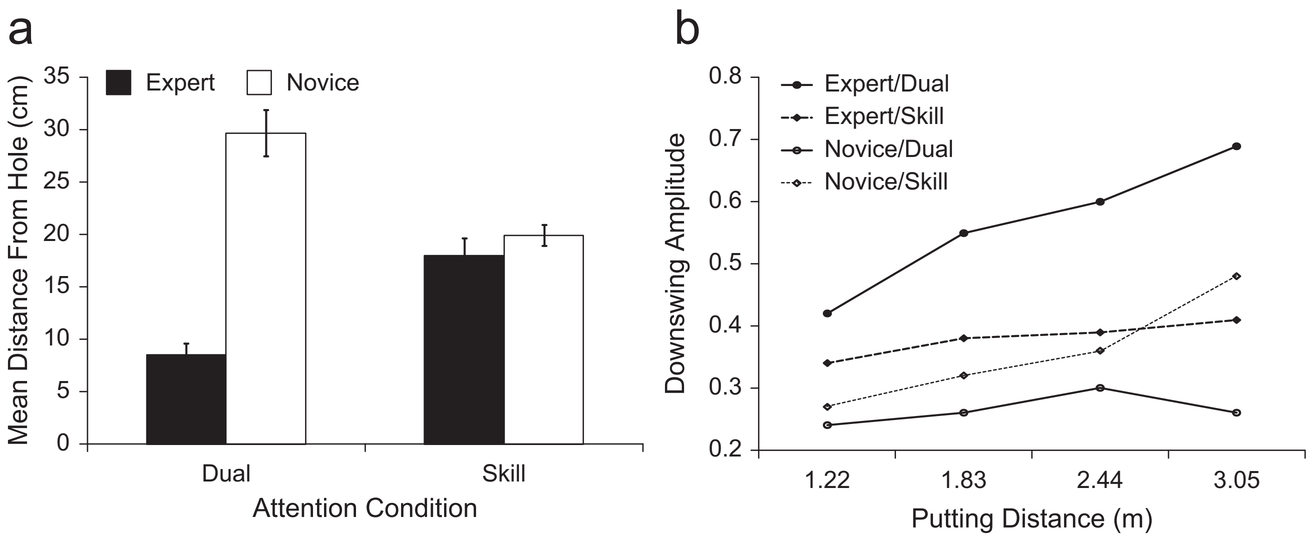

Fig 2. Mean distance from the hole for experts and novices for putts made in two different secondary task conditions (skill-focused and dual-focus; a) and the relationship between the downswing amplitude and putting distance for experts and novices in those conditions (b). Reprinted and modified from "From Attentional Control to Attentional Spillover: A Skill-Level Investigation of Attention, Kinematic, and Performance Outcome Relations," by S.L. Beilock & R. Gray (in press), *Human Movement Science*. Reprinted and modified with permission.

an external focus of attention (the basket), shot accuracy was greater and there was a reduction in integrated EMG activity in both the biceps and triceps as compared to performance in an internal-focus condition (wrist movement). The decrease in EMG activity in the external-focus condition can be interpreted as an improvement in movement economy, because less activity is being used to produce a more successful movement. Lohse et al. (2010) reported a similar finding in the dart-throwing experiment described earlier. Throwing accuracy was significantly higher and EMG activity in the tricep muscles was significantly less in the external-focus condition than in the internal-focus condition.

Pressure has also been shown to influence economy of movement. Coombes, Higgins, Gamble, Cauraugh, and Janelle (2009) reported that under conditions of anxiety, muscle activity increases and movements are produced with more force (leading to a decrease in movement economy) as a result of increased excitability of the corticospinal tract.

Changes in Motor-Control Strategy

A final type of movement effect that has been linked to attention involves changes in the motor-control strategy used during skill execution. Consider how a golfer successfully putts from different distances on the green. One possible control strategy is to alter the force at putter–ball contact by varying the length (or amplitude) of the putting stroke. An alternative strategy is to use the same stroke amplitude for each putt but vary the stroke velocity, increasing the velocity for larger distances. Research examining putting kinematics has shown that the patterns of movement observed for expert golfers are highly consistent with the former strategy (downswing amplitude variation) while the patterns of movement observed for novice golfers are more consistent with the latter strategy (Delay, Nougier, Orliaguet, & Coello, 1997).

Beilock and Gray (in press) investigated how these putting-control strategies are influenced by shifts in a putter's attentional focus. In a first experiment, attentional control was manipulated via two different secondary tasks: There was a *dual-task condition*, in which participants judged the frequency of a tone presented during their stroke, and a *skill-focused condition*, in which participants judged whether the tone occurred closer to the starting or end point of the segment of the stroke in which the tone was presented. As shown in Figure 2A, for experts, putting performance was least accurate in the skill-focused condition. As shown in Figure 2B, this decline in accuracy was significantly mediated by a reduction in the strength of the relationship between stroke amplitude and distance (and a significant increase in the strength of the relationship between stroke velocity and distance, not shown). In other words, when attention was directed to execution of the skill, experts switched to using the novice motor-control strategy for putting from different distances.

In a second experiment, attentional control was manipulated by introducing the possibility that participants would stop their swing midstroke in response to an auditory signal, thus pushing them to exert added control over step-by-step execution. Stop trials were interleaved with normal-putting trials. Relative to baseline performance, expert golfers putted significantly worse on the interleaved normal putts than novices did. Again, this decline in performance was mediated by a change in the motor-control strategy: The strength of the relationship between downswing amplitude and putting distance decreased for interleaved trials, whereas the strength of the relationship between swing velocity and distance increased. Beilock and Gray proposed that having to stop the putter on some trials induced an "attentional spillover" effect whereby the focus of attention was shifted to skill execution (which is known to harm expert performance) during nonstop trials.

Summary and Conclusions

Recent research has reported several movement effects that occur as a result of shifts in the attentional focus induced by instruction, dual-task conditions, and/or performance pressure. When a performer shifts his or her attention "inward" to the execution of movement, there is an associated change in movement variability (either an increase or decrease depending on the aspect of movement being measured), an increase in the cross-correlation between movements of multiple joints indicative of increased rigidity, a decrease in economy of the movement (i.e., the ratio energy/output), and a change in motor-control strategy. All of these effects are consistent with a regression to an earlier (novice) stage of skill acquisition involving step-by-step declarative processes and freezing of *df* in movement. It will be interesting for future research to investigate further connections between effects that have been typically labeled as "cognitive" or "attentional" and movement-related effects. It is only by linking these multiple levels of analysis that a complete theoretical account of skilled performance can be developed. It will also be important for future research to investigate the relationship between attentional focus and movement under more ecologically valid conditions, as it has been recently suggested that attentional effects observed in the lab may not be indicative of attention control during actual sports competition (Oudejans, Kuijpers, Kooiman, & Bakker, 2011).

On a practical level, these findings are important because they identify specific aspects of movement execution that a coach and struggling performer can address during practice. Previous "choking under pressure" interventions have primarily focused on what happens long before the stressful event occurs—for example, using videotaping during practice (Beilock & Carr, 2001) or reducing the amount of explicit knowledge used during acquisition of a skill (Masters, 1992). The experiments described here identify specific aspects of performance (e.g., the club head angle in putting, the rigidity of joint movements in climbing, or increased muscle force in throwing) that could be addressed with training to correct the performance of an athlete who has recently failed under pressure or is in a performance slump (Gray, 2004) and/or to prevent choking in the future. For example, if the force of a golfer's grip increases under pressure conditions, a coach could use analogy instructions (e.g., "imagine you have an open tube of toothpaste between your hands and the contents must not be pushed out") to both address the specific biomechanical problem and shift attention away from skill execution.

Recommended Reading

Baumeister, R.F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology, 46*, 610–620. Description and analysis of the two main theories of "choking under pressure."

Beilock, S.L. (2010). *Choke: What the secrets of the brain reveal about getting it right when you have to*. New York, NY: Simon & Schuster. Overview of research on attention and pressure, written for a general audience.

Vereijken, B., Vanemmerik, R.E.A., Whiting, H.T.A., & Newell, K.M. (1992). Free(z)ing degrees of freedom in skill acquisition. *Journal of Motor Behavior, 24*, 133–142. First paper to show evidence of "freezing" and "freeing" degrees of freedom.

Wulf, G., & Prinz, W. (2001). (See References). Review of research examining the effects of attention on skilled performance.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This work was supported by a grant from the National Science Foundation awarded to author R.G.: Faculty Early Career Development Program (# 0239657).

Note

1. The primary alternative to these theories is the proposal that pressure serves as a distraction that interferes with the processing of task-relevant information. For recent evidence in support of this theory, see Oudejans, Kuijpers, Kooiman, and Bakker (2011).

References

Beilock, S.L., & Carr, T.H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*, 701–725.

Beilock, S.L., & Gray, R. (2007). Why do athletes "choke" under pressure? In G. Tenenbaum & B. Eklund (Eds.), *Handbook of sport psychology* (3rd ed., pp. 425–444). Hoboken, NJ: John Wiley & Sons.

Beilock, S.L., & Gray, R. (in press). From attentional control to attentional spillover: A skill-level investigation of attention, kinematic, and performance outcome relations. *Human Movement Science*.

Bernstein, N.A. (1967). *The coordination and regulation of movements*. Oxford, UK: Permagon Press.

Cooke, A., Kavussanu, M., McIntyre, D., & Ring, C. (2010). Psychological, muscular and kinematic factors mediate performance under pressure. *Psychophysiology, 47*, 1109–1118.

Coombes, S.A., Higgins, T., Gamble, K.M., Cauraugh, J.H., & Janelle, C.M. (2009). Attentional control theory: Anxiety, emotion, and motor planning. *Journal of Anxiety Disorders, 23*, 1072–1079.

Delay, D., Nougier, V., Orliaguet, J.-P., & Coello, Y. (1997). Movement control in golf putting. *Human Movement Science, 16*, 597–619.

Gray, R. (2002). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance, 5*, 1131–1148.

Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking and slumps. *Journal of Experimental Psychology: Applied, 10*, 42–54.

Lee, D.N., Lishman, J.R., & Thompson, J.A. (1982). Regulation of gait in long jumping. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 449–459.

Lohse, K.R., Sherwood, D.E., & Healy, A.F. (2010). How changing the focus of attention affects performance, kinematics and electromyography in dart throwing. *Human Movement Science, 29*, 542–555.

Masters, R.S.W. (1992). Knowledge, knerves and know-how—The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology, 83*, 343–358.

Oudejans, R.R.D., Kuijpers, W., Kooiman, C.C., & Bakker, F.C. (2011). Thoughts and attention of athletes under pressure: Skill-focus or performance worries? *Anxiety, Stress, and Coping, 24*, 59–73.

Pijpers, J.R., Oudejans, R.R.D., Holsheimer, F., & Bakker, F.C. (2003). Anxiety-performance relationships in climbing: A process-oriented approach. *Psychology of Sport and Exercise, 4*, 283–304.

Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin and Review, 8*, 648–660.

Zachary, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67*, 304–307.