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Perceiving movement patterns: Implications for skill evaluation, correction and development

Percepción de los patrones de movimiento: Implicaciones para la evaluación, corrección y el desarrollo de habilidades

Georgia Giblin[1], Damian Farrow[2], Machar Reid[3], Kevin Ball[4], Bruce Abernethy[5]

1. ISEAL, Victoria University, Melbourne, Australia. Tennis Australia, Melbourne, Australia.
2. ISEAL, Victoria University, Melbourne, Australia. Australian Institute of Sport, Canberra, Australia.
3. Tennis Australia, Melbourne, Australia. School of Sports Science, Exercise and Health, University of Western Australia, Perth, Western Australia.
4. ISEAL, Victoria University, Melbourne, Australia.
5. School of Human Movement Studies, The University of Queensland, Brisbane, Australia.

Abstract

Skill practitioners such as coaches, judges, and rehabilitation specialists rely heavily on the visual observation of movement to analyse performance, concomitantly performers of movement rely heavily on kinaesthetic sensitivity to produce movements of desired precision. The observation of movement errors (by coaches or therapists) and the correction of movement errors (by performers or patients) depend on fundamentally different perceptual systems that may differ in their sensitivity, units of control and trainability. This paper first examines the skill of perceiving fundamental movement characteristics and patterns (i.e., movement kinematics) by reviewing sport expertise literature that has investigated the capabilities of both expert performers and expert observers. Important expertise related differences in visual perceptual skill are discussed with a focus on perceptual and motor contributions to perceptual skill. Theories related to the perception of others movement patterns such as common coding are reviewed with a focus on implications for skill practitioners. Limitations in the current visual observation literature are considered, in particular the need to more directly examine the perceptual capabilities of skill practitioners to reliably differentiate changes in kinematics. The critical parallel issue of the kinaesthetic sensitivity of the patient or athlete is also reviewed, highlighting the need to know the magnitude of the differences between visual and kinaesthetic sensitivities for changes in movement kinematics in order to understand some of the challenges involved in matching detection of movement pattern errors to correction of these errors. Future research directions are discussed; particularly key methodological issues which may help directly establish perceptual sensitivity.

Key words: perception; observation; kinematics; kinaesthesis; expertise.

Resumen

Profesionales en habilidades, tales como entrenadores, jueces y especialistas en rehabilitación, dependen en gran medida de la observación visual para analizar el rendimiento, así como aquellos que realizan el movimiento dependen en gran medida de la sensibilidad cinestésica para producir movimientos con precisión. La capacidad de determinar de forma precisa las características fundamentales del movimiento a través de la observación es fundamental para ofrecer una evaluación, diagnóstico y corrección eficaces. Del mismo modo, la capacidad de controlar con precisión la ejecución del movimiento es central para la producción de patrones de movimiento deseados. La observación de errores del movimiento (por entrenadores y terapeutas) y la corrección de estos errores (por atletas o pacientes) dependen fundamentalmente de diferentes sistemas de percepción que pueden diferir en su sensibilidad, unidad de control y capacidad de entrenamiento. En este trabajo se examina en primer lugar, la habilidad de percibir las características del movimiento y los patrones fundamentales (es decir, la cinemática del movimiento) mediante una revisión bibliográfica de expertos del deporte que han investigado tanto las capacidades de los atletas como de los observadores expertos. Importantes diferencias en el conocimiento especializado referente a las habilidades en percepción visual son discutidas, centrándose en las contribuciones perceptivas y motoras a la habilidad de percepción. Las teorías relacionadas con la percepción de otros patrones de movimiento, tales como la codificación común, son revisados haciendo especial hincapié en las implicaciones para los practicantes en habilidades. A continuación se consideran las limitaciones en la bibliografía actual sobre la observación visual, en particular, la necesidad de examinar de forma más directa las capacidades perceptivas de los atletas para diferenciar de forma fiable los cambios cinemáticos. Además, de forma paralela, se analiza una cuestión clave como es la sensibilidad cinestésica del paciente o deportista, destacando la necesidad de conocer la magnitud de las diferencias entre las sensibilidades visuales y cinestésicas durante los cambios en la cinemática del movimiento, con el fin de comprender algunos de los desafíos involucrados en la relación entre la detección de errores en patrones de movimiento y la corrección de estos errores. Por último se discuten futuras líneas de investigación; en particular aquellas cuestiones metodológicas clave que pueden ayudar a establecer directamente la sensibilidad perceptiva.

Palabras clave: percepción; observación; cinestesia; experiencia.

Correspondence/correspondencia: Georgia Giblin
ISEAL, Victoria University, Melbourne, Australia. Tennis Australia, Melbourne, Australia.
Email: georgia.giblin@live.vu.edu.au

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Introduction

Movement patterns play an integral role in everyday life from simple tasks such as picking up a coffee cup to more complex skills like returning serve in a game of tennis. In order to perform such tasks effectively a high level of coordination is necessary. These movements and their associated kinematics (i.e., the spatial and temporal components of motion including position, velocity and acceleration) form the basis for any coordinated movement, whether in a daily living environment or a more dynamic sports setting. Given the functional importance of movement patterns, it would seem that the ability to analyse these patterns and detect performance errors and/or areas for improvement is also critically important. Movement pattern analysis is a primary task for many skill learning practitioners, be it physical therapists assessing movement after injury or surgery or physical education teachers or coaches assessing and adjusting the fundamental motor skills of their pupils. The ability to detect the critical aspects of motion is pivotal to the role of a skill practitioner and directly impacts on the likely efficacy of the resultant treatment or feedback that follows the perceptual evaluation. The success of the practitioner is likely dependent on their ability to discriminate often small yet important kinematic differences in movement or technique.

While the perceptual sensitivity of observers is critical for movement pattern analysis, it is also crucial we seek to understand the limits of kinaesthetic sensitivity. Clearly the magnitude of the differences between these two processes is of great importance. Skill practitioners may have heightened sensitivity to detecting changes but if the performer is not able to detect a change in their movement pattern, feedback or movement correction will be ineffective. Indeed attempts to make corrections which are below the performer's threshold for change detection may actually increase rather than decrease the deviation of the produced movement pattern from the desired (target) pattern. Despite these important parallel issues, the ability of skill practitioners to perceptually discriminate changes in movement has received little research attention and is poorly understood. Likewise, understanding of the perceptual sensitivity of the performer or patient to changes in their own movement production is equally limited.

The aim of this paper is to highlight the importance of understanding both (i) how sensitive skill practitioners are to visually perceiving changes in movement produced by others and (ii) how kinaesthetically sensitive performers of movement skills are to changes in the movements they produce. Promising methodological approaches and future directions are suggested with the aim of enhancing both the understanding of the visual perceptual skill of practitioners when evaluating movement and the concordance between their visual sensitivity to detect changes in movement and their athlete/client's capability to detect and control, kinaesthetically, changes of similar magnitude. The important role of feedback is considered with regard to both visual and kinaesthetic sensitivity.

Perceptual Expertise

Expert performers, particularly those performing interceptive actions, are known to be characterised by their superior visual perceptual skills, especially their skills to make predictive judgements from observation of complex movement patterns of opponents. The ability to use advance postural or kinematic information has been demonstrated to be critical to success in fast ball sports, particularly when time and speed constraints require a reaction, often before the opponent has completed their skill (Abernethy & Zawi, 2007; Farrow & Abernethy, 2003). For example, in order to intercept a high velocity tennis serve it is necessary to commence many aspects of the movement response prior to the opponent striking the ball. The majority of research examining the relationship between visual perception and kinematics has focused on advance cue utilisation – the ability to make accurate predictions based on the information available prior to ball contact from the opponent's movement pattern (Abernethy & Russell, 1987). Studies on visual-perceptual skill in racquet sports have found expert players perform better than non-experts under occlusion conditions that occur at or 300 ms prior to ball-racquet impact (Farrow, Abernethy, & Jackson, 2005) and that experts have the ability to use and interpret information gained from the pre-impact motion of the racquet and the earlier motion of the arm holding the racquet while novices can only use information from the racquet (Abernethy & Russell, 1987). The ability to use advance information has been extended to deceptive movements, with experts demonstrating an increased ability to use advance information to discriminate deceptive from genuine movements common in interceptive sports. Jackson, Warren, and Abernethy (2006) found that expert players were less susceptible to deceptive movements suggesting that experts were better able to interpret and use advance deceptive information to inform their judgments.

Collectively these findings demonstrate that expert visual-perceptual skill is reliant on the pick-up of earlier information sources closely connected to the production of the particular movement sequence (Farrow & Abernethy, 2003). Specifically, the experts pick up of proximally (earlier) occurring advance information suggests their advantage lies in their ability to perceive and understand kinematic information – a contention supported through studies of "Point Light Displays" (PLDs) presenting only kinematic information (Abernethy & Zawi, 2007; Kozlowski & Cutting, 1977; Shim & Carlton, 1997). Further, to their ability to utilize advance information, it appears skilled performers adopt a more 'global' rather than 'local' strategy, relying on multiple sources of information to inform their judgments (Williams, Huys, Cañal-Bruland, & Hagemann, 2009). While coaches, teachers and other practitioners who assess skill learning do not necessarily experience the same time constraints as are imposed on performers, their ability to rapidly pick up and interpret the available biomechanical information is nevertheless crucial to providing timely and accurate feedback. Interestingly, despite the absence of time stress there appears to be commonality in how skill practitioners perceive the kinematics of an athlete when making a judgement and how expert performers make judgements of the opponent's intent (Ste-Marie, 1999).

Ste-Marie (1999) examined differences in novice and expert judges who viewed a series of gymnastics manoeuvres on video and were asked to predict the upcoming elements and associated errors once the video had been stopped. Expert judges were significantly better at anticipating the upcoming action than novices and, regardless of skill level, when the correct manoeuvre was anticipated a more accurate score resulted. Ste-Marie (1999) proposed that expert judges were better at understanding the biomechanical information available to them, and were therefore better at determining the following consequential elements of the movement sequence that followed. As a result of the early recognition of redundancy, the information processing demands placed on the expert judges were speculated to be reduced and in turn provided the judge with more attentional resources to allocate to the analysis of performance. Based on the findings demonstrated with athletic performers (Abernethy & Zawi, 2007) and those of Ste-Marie (1999) with judges it seems reasonable to suggest that expert skill practitioners in the field of coaching, physical therapy or teaching may likely also possess an enhanced ability to understand available biomechanical information, and use this to detect and categorise changes in movement patterns.

While the expert performer's attunement to pre-contact kinematics is well established, the use of the temporal occlusion approach with non-sports specific response methods have been criticised for failing to consider the reciprocal relationship between perception and action and it's underpinning processes (Van der Kamp, Rivas, Doorn, Savelsbergh, & Bennett, 2008). For instance, it is argued that the expert's superior capability to use pre-flight kinematics to predict outcome direction is supported by the ventral system when a temporal occlusion approach is adopted. However, such an approach overlooks the contribution of the dorsal system as a movement response is not required. Van der Kamp et al. (2008) argued that the constant interaction between these two systems in necessary for skilled perception and anticipation. Indeed, a further related criticism of much of the anticipation research stems from the lack of representative task designs in which stimuli are reflective of the organism's natural environment and allow for functional movements responses (Dicks, Button, & Davids, 2010). Dicks et al. (2010) demonstrated that gaze and movement behaviour when attempting to save a penalty kick in soccer differed depending on the task constraints (verbal versus movement response). The contribution of the ventral and dorsal systems to anticipatory skill when representative movement responses are used requires further exploration.

Motor Expertise

The link between perception and action has been a principal topic of investigation in cognitive science. Traditionally, it was considered that perception and action could not directly interact, rather some sort of translation had to occur (Prinz, 1997). In recent years, this traditional theory has been challenged by theories such as embodied cognition and common coding which suggest that perception and action are directly linked. Such theories have been used to directly examine the effect of motor expertise on an observer's ability to predict and discriminate between observed actions (Aglioti, Cesari, Romani, & Urgesi, 2008; Pizzera, 2012). Further, non-representational theories such as the perception of other's affordances have also been examined in relation to motor expertise. Affordances refer to the opportunities for action provided by the environment for an organism/person (Fajen, Riley, & Turvey, 2009). To use team sports as an example, throughout the course of a game, athletes are exposed to numerous opportunities for action such as passing the ball, eliminating a defender or intercepting a moving ball, all of which are afforded to them by their action capabilities and the changing environment. Research has shown that humans not only have the capability to perceive affordances for themselves (Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989) but for others (Stoffregen, Gorday, Sheng, & Flynn, 1999). Further, athletes have been shown to be more sensitive to kinematic information when judging affordances. Weast, Shockley, and Riley (2011) showed that basketball players were superior to a non-basketball control group at perceiving basketball-relevant affordances for others. If motor experience facilitates enhanced perception of others affordances through the perception of kinematics, it is likely that skill practitioners with motor experience in the action they are viewing are likely to perceive the affordances of others with greater accuracy.

Common coding theory suggests that perceptual and motor systems share representations for the same actions (Prinz, 1997). As a consequence, observing and anticipating someone else's movement patterns triggers activation of the observer's coded representations for their production of the same movement. Common coding theory is supported by neural evidence of mirror neurons which fire when observing or producing a specific action (Buccino, Binkofski, & Riggio, 2004) and by "Functional Magnetic Resonance Imaging" (fMRI) which has shown that mirror neuron activation is influenced by motor expertise in ballet dancers (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006) and athletes (Bishop, Wright, Jackson, & Abernethy, 2013; Wright, Bishop, Jackson, & Abernethy, 2010; Wright, Bishop, Jackson, & Abernethy, 2011). Schütz-Bosbach and Prinz (2007) proposed that observers should be perceptually better attuned to actions that they have experience performing, with greater experience resulting in more accurate perception of the action. In support of this contention, motor experience has been found to assist the perception of joint angles when judging a balance beam skill in gymnastics (Pizzera, 2012). Judges with specific motor expertise (i.e., those with experience performing the exact skill which they were judging) significantly outperformed those with no motor experience in the specific skill. In particular, judges with motor expertise appeared to be more sensitive to the angles of the arms and legs during skill execution making significantly more correct judging decisions in relation to these limb segments. In addition, motor expertise has been found to be beneficial when judging the intentions of other people performing a basketball pass. Sebanz and Shiffrar (2009) found that experts were able to make more accurate predictions of others intentions when only kinematic information was available, suggesting experts may have used their own motor experience to assist perception. The expert advantage evident in the perception of deceptive movements is typically attributed to either perceptual (Jackson et al., 2006) or motor (Sebanz & Shiffrar, 2009) expertise. More, recently Cañal-Bruland and Schmidt (2009) examined the contribution of both perceptual and motor expertise to perceptual judgments of deceptive movements and found that as in previous research experts were better able to recognize deceptive movements, yet motor expertise did not significantly contribute to performance.

While some research suggests motor expertise is advantageous for anticipation, the research is not unequivocal. Abernethy and Zawi (2007) reasoned that the common coding theory may account for expert badminton players enhanced performance on anticipation tasks given they are superior to novices in both perception and stroke production. In addition, they suggested experts may be more attuned to the proximal-distal kinematic evolution of the stroke given their previous expertise performing it. Results provided little evidence to support these common coding hypotheses. Superior experience and skill among the experts did result in increased direction prediction accuracy yet the information used by experts did not appear to be linked to the segmental kinematics involved in the movement production. Prediction accuracy was not increased with the availability of linked segments among experts; rather vision of linked segments appeared to provide more benefit to the novice performers. In contrast, Abernethy, Zawi and Jackson (2008) did find support for common coding when they examined the anticipatory skill of the same badminton players to predict shot depth. The addition of linked segment information was beneficial in enhancing depth predication accuracy for the expert but not the novice players. Changing stroke depth requires force modulation and is likely influenced by the summation of forces across joints and therefore provides a better test of common coding, whereas changing stroke direction may be achieved by a singular segment. The literature surrounding common coding and the impact of motor experience on perception while intuitively appealing is far from compelling and is a fruitful area for further research.

Visual sensitivity to changes in movement pattern information

While the perception of kinematics as an advance information source has been well studied (Abernethy, 1990; Abernethy & Zawi, 2007; Shim, Carlton, Chow, & Chae, 2005) the measurement of sensitivity to change has not. As a consequence there is little existing literature to help address the question of what degree of change is required in order to perceive a technical change in a performer’s movement pattern. The capacity for coaches, teachers, or physical therapists to detect change is critically important for error detection and correction, while for sports judges accurate perception of change is required to precisely differentiate performed actions from the desired model, or compare actions across individuals or teams. The absence of a systematic evidence base on the error detection sensitivity of movement skill analysts is a significant shortfall in current understanding. Typically, the research has focused on recognition (Pollick, Fidopiastis, & Braden, 2001) or anticipation tasks (Abernethy & Zawi, 2007) with few attempts to extend the research to examine the detection of perceptible differences in kinematics.

The notion of perceptible kinematic difference has been explored in a clinical setting, particularly with regards to rehabilitation. Physical therapists commonly use visual observation to evaluate movement in order to establish deficits and generate treatment plans. Successful treatment relies on accurate observation and assessment, both within and between practitioners. The limited available research has shown that visual observation is a reasonably accurate tool for analysing movement patterns (Bernhardt, Matyas, & Bate, 2002; Whatman, Hume, & Hing, 2013). For example, physical therapists observing the gait symmetry of patients following a cerebrovascular accident were found to accurately judge time spent in stance on the weaker leg (Spencer, Goldie, & Matyas, 1992), while physiotherapists have been found to reliably identify poor dynamic pelvis and knee alignment in young athletes (Whatman et al., 2013). Typically, the research has used an expertise approach similar to that used within a sports domain to investigate the influence of experience on visual perception of movement. Bernhardtet et al. (2002) demonstrated that experienced physiotherapists could accurately discriminate differences in kinematics (speed and jerkiness) by cerebrovascular patients in an upper limb transport task, but the accuracy of judgements was not dependent on experience, with the less experienced therapists performing similarly to the highly experienced therapists. In contrast, Weir, Holmes, Andrews, Albert, Azar and Callaghan (2007) found the ability to detect changes in trunk posture was dependent on experience. Results revealed observers could detect changes as small as 2° in trunk flexion/extension, with novice participants recording a lower sensitivity and increased variability than the intermediate and expert participants (Weir et al., 2007). Interestingly, Weir et al., (2007) considered the effect of movement direction (increasing or decreasing angular position), movement plane (flexion/extension) and experience on perceptual discrimination ability. Both experience and movement direction were significant factors on perceptual ability while the movement plane (flexion/extension versus lateral bending) did not appear to affect sensitivity.

While it is clear that in a controlled, context-specific setting, precise observation and judgement of kinematics is possible, such methodologies have not yet been applied to the complex, high-speed and highly coordinated movements typical of a more dynamical environment such as sport, where observation is made by coaches and teachers. Practically, these studies raise interesting questions which need to be considered by skill practitioners when observing movement pattern information. Some of the questions are discussed in the next section (Future Research).

Kinaesthetic sensitivity for movement pattern information

The majority of research surrounding what an athlete can "feel" through movement exists in a clinical setting, and revolves around the notion of proprioceptive acuity. Proprioceptive acuity is defined by Muaidi, Nicholson and Refshauge (2008, p.371) as "the ability to sense joint positions, movement and force of muscle contraction and to discriminate movements of limb segments individually and relative to each other". The bulk of the research on proprioceptive acuity has examined differences in proprioceptive acuity after injury or surgery (Cooper, Taylor, & Feller, 2005; Fischer-Rasmussen & Jensen, 2000) or during rehabilitation (Cooper et al., 2005). One approach that has been widely used in a clinical setting to establish perceivable difference is the "just noticeable difference" (JND) method.

Threshold measurements, including absolute thresholds and just noticeable difference have long been used in psychophysics to objectively measure the relationship between experimental stimuli and sensation in all senses. Two types of thresholds are common measures in psychophysics (Kantowitz, Roediger III, & Elmes, 2008); absolute thresholds and difference thresholds. Absolute thresholds are used to identify the intensity or level of a stimulus that is needed to be detected some portion of the time, and is commonly obtained using the method of limits (Kantowitz et al., 2008). Difference thresholds (JNDs) are used to measure the smallest detectable difference between two stimuli correctly judged 50% of the time (Kantowitz et al., 2008). Proprioceptive acuity in flexion and extension of the normal knee joint using different methods of measurement (detection of passive movement, active reproduction of a joint angle, and active movement discrimination) have found proprioceptive acuity to range from 0.5°-6.5°. Proprioceptive acuity in healthy active participants is as little as 1.37° for internal rotation and 1.6° for external rotation movements of the knee (Muaidi et al., 2008). Given the significant evidence suggesting visual perceptual expertise is influenced by motor expertise (Aglioti et al., 2008; Cañal-Bruland, van der Kamp, & van Kesteren, 2010; Pizzera, 2012), it seems critical to consider motor expertise when examining the kinaesthetic sensitivity of performers. In a separate study, Muaidi et al., (2009) demonstrated that elite athletes exhibit significantly greater proprioceptive acuity for knee rotation compared to non-athletes. More recently, research has demonstrated that involvement in high-intensity skilled exercise is associated with increased proprioceptive sensitivity for flexion/extension movements of the knee (Courtney, Rine, Jenk, Collier, & Waters, 2013). Combined these findings suggest performers are highly sensitive to changes in their own movements and that motor expertise is beneficial for kinaesthetic sensitivity, particularly in the knee joint, yet whether these findings can be generalised to other joints is unclear.

Interestingly Tan, Srinivasan, Eberman and Cheng (1994) found JNDs in joint angle followed a proximal-distal trend not unlike the sequencing used by experts performing interceptive actions. Using a haptic interface, JND for the wrist, elbow and shoulder joints were measured. Results showed joint angle sensitivity was better at proximal joints, with a JND of 0.8° at the shoulder compared to a JND of 2° for the distal joints of the elbow and wrist. Tan et al., (1994) suggest that the increased sensitivity of proximal joints help to control end points (e.g. fingers) accurately, and that accuracy in placing end points of a linked system or chain is dependent on the angular sensitivity of the proximal joint or the joint further from the end point. These findings raise interesting questions, specifically about how the visual sensitivity of joint movement can be matched to the kinaesthetic sensitivity, particularly if the sensitivity for each joint is dependent on speed, direction and motor experience. Overall, clinical research using a JND paradigm has shown only a relatively small degree of change is required for a difference to be detected by the performer; however whether these findings are transferable to complex skills typically viewed by skill practitioners or coaches is unknown.

Future Research

A potential problem when examining expertise is that expert performers are frequently unable to accurately self-report on the source of their expertise (Abernethy, 1994). A number of methodological approaches from experimental psychology may provide a useful avenue for future research directions examining expert perception of kinematics. In particular, future research needs to consider methodologies which will help to quantitatively answer exactly what degree of change can be perceived by an observer. One possible methodology stems from literature examining the relationship between perceptual processing and awareness (Cheesman & Merikle, 1986; Marcel, 1983) and has focused on whether the meaning of visual stimuli is perceived in the absence of conscious processing (awareness). In order to address this question, researchers have adopted the use of subjective and objective threshold measures. A subjective threshold corresponds to a level where observers claim not to be able to detect or perceive perceptual information at greater than chance levels, whereas an objective threshold relates to the actual level where perceptual information is discriminated at chance levels. These threshold measures have the advantage of expressing the exact degree of change an observer can consciously detect as well as the extent of change to which they can (often unconsciously) respond. Despite this research using thresholds to detect changes in kinematics is currently extremely limited.

Cheesman and Merikle (1984) used a stroop priming task to demonstrate that at a subjective threshold (where participants claimed they could not detect stimuli) actual mean detection performance was well above chance levels (53%-75% correct). Participants were required to identify four pattern masked stimulus or prime words (blue, green, red or yellow) and estimate their performance. Subjective thresholds for awareness were established for each participant by systematically decreasing the prime-mask stimulus onset asynchrony until participants reported they were completely guessing. At the subjective threshold, observers correctly identified the prime word 66% of the time. Importantly this finding demonstrates that priming occurs in the subjective threshold condition even though participants claim to be unable to distinguish between primes.

The application of threshold measures to perceptual problems such as those confronted by skill practitioners has the potential to establish the limits of conscious and unconscious processing when viewing kinematics. Currently, skill practitioners rely heavily on subjective judgments when observing and diagnosing, yet just how accurate or sensitive they are to perceiving changes in movement is unknown. Threshold measurements would enable quantitative analysis of specific joint kinematics, allowing researchers to determine if perception of change is influenced by the joint being viewed. In addition, the plane and direction of movement, along with movement speed need to be considered. Specifically, such approaches will allow researchers to determine for movements around which joints observers are most sensitive to perceiving changes. Further, if motor experience does indeed facilitate perception as the results of Pizzera (2012) suggest, it may be plausible to suggest that perception is influenced by those aspects performed with greater expertise. Additional research is required to assess the generalizability of these findings to other movement patterns and skills. The knowledge gained from such research has the potential to influence the type and precision of feedback provided by practitioners.

The JND paradigm often used in clinical research provides well established methods suitable to examining joint-specific kinaesthetic sensitivity. An interesting future direction would be to consider whether motor expertise facilitates smaller joint JNDs (increased sensitivity) as suggested by Muaidi et al., (2009) and Courtney et al., (2013). Han, Waddington, Adams and Anson (2013) suggest that proprioception is site specific rather than a global or general ability. If this is the case, and proprioception is joint specific, an interesting question surrounds whether athletes would have increased joint sensitivity (lower JNDs) in the joints which they use most in movement patterns common in their sport. If this is the case, the implications for observers need to be considered, especially the magnitude of difference between visual and kinaesthetic sensitivity.

A major consideration stemming from this review concerns the precision and type of feedback which can be provided to performers after considering the relationship between visual and kinaesthetic sensitivities. Traditionally, feedback is presented to students, pupils or patients based on the visual observation made by a teacher, coach or therapist. The accuracy of these perceptual judgements is critical to providing effective feedback. While the provision of accurate feedback is often reliant on the perception of small kinematic changes, movement production is inherently variable, and small changes in kinematics are often present despite successful skill execution. While existing research has shown visual observation is generally reliable (Bernhardt et al., 2002; Whatman et al., 2013) advancements in feedback technology have the potential to facilitate perceptual sensitivity or awareness. In complex, highly coordinated, high velocity movements, accurate perception of movement is likely to be compromised, and live visual observation may no longer be an accurate tool to interpret the kinematics of interest. In these instances, the use of technology is likely to assist the observer in making a more accurate judgment. Phillips, Farrow, Ball and Helmer (2012) argue that feedback needs to be considered from a measurement perspective as well as a relevance perspective. If the visual system is no longer capable of accurately judging a movement, then alternate methods need to be considered. From a relevance perspective, the feedback which is provided to the athlete or pupil must be able to be adapted or adjusted by the athlete or pupil (Phillips et al., 2012). For instance, if visual sensitivity is superior to kinaesthetic sensitivity any feedback provided at the most precise level of visual sensitivity will be unable to be used effectively as such precision cannot be matched, interpreted or used kinaesthetically. For this reason, it is critically important the sensitivities of both the perceptual and kinaesthetic systems be considered when providing feedback to athletes, patients or pupils. To date, limited research exists on how change sensitivity in these two domains interact and should be used to guide feedback specificity and provision.

Conclusion and implications

This review has highlighted the importance of accurately perceiving movement patterns across a wide range of domains. The extant literature demonstrates a large sampling bias towards the athletic population. Sustained research investigating specialist populations such as coaches, teachers, physical therapists and judges coupled with emerging theoretical frameworks such as common coding is presently lacking.

Clinical research using a JND approach has shown the perceptual system to be highly sensitive to perceiving change, with observers capable of visually detecting relatively small changes in movement, and performers capable of kinaesthetically detecting (feeling) small changes in their own movement patterns. However a key gap that is evident is the absence of literature directly examining the ability of skill practitioners to visually perceive and discriminate changes in kinematics. If the perceptual system is indeed as sensitive as some clinical research suggests, is there value in this sensitivity or will the resultant feedback be too precise for a performer to control and implement? Further, it is unknown if this sensitivity extends to dynamic settings such as those experienced in a sporting environment or if previous motor experience in the skill being observed effects a practitioner’s sensitivity to perceiving changes in movement patterns. Alternative methodologies based on JND/threshold detection that have long existed in psychophysics have the potential to answer some of these questions by providing a degree of precision not currently reported. The perceptual skill of observers is a critical component in the development of expertise and further work using alternate methods to the traditional sport performer expertise approach are needed to more fully understand both the visual and kinaesthetic perceptual capabilities of skill coaches/therapists and their athletes/patients.

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