# Skill and experience impact global and local biological motion processing

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#### Abstract

During biological motion perception, individuals with perceptual experience learn to use more global processing, simultaneously extracting information from multiple body segments. Less-experienced observers may use more local processing of individual body segments. In this study, we examined how skill impacts the neural processing of motion information. Skilled (N = 21) and less-skilled (N = 19) soccer players anticipated temporally occluded videos of penalty kicks under normal, blurred, or spatially occluded (hips-only) viewing conditions, with the latter two conditions emphasizing global and local information respectively. EEG was used to measure parietal alpha and beta oscillations. Skilled players outperformed less-skilled players, albeit both skill groups were less accurate under blurred and hips-only conditions. Skilled performers showed significant decreases in bilateral parietal beta power in the hips-only condition, suggesting a greater reliance on global information. Additionally, the hips-only condition for both skill groups, suggesting this condition elicited a shift towards more local processing. Our novel findings demonstrate that skill and experience impact how motion is processed.

# Skill and experience impact global and local biological motion processing

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None.

#### Data Availability

Data are publicly available at https://github.com/bradydecouto/GlobalLocalSoccer

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# ABSTRACT

During biological motion perception, individuals with perceptual experience learn to use more global processing, simultaneously extracting information from multiple body segments. Less-experienced observers may use more local processing of individual body segments. In this study, we examined how skill impacts the neural processing of motion information. Skilled (N = 21) and less-skilled (N = 19) soccer players anticipated temporally occluded videos of penalty kicks under normal, blurred, or spatially occluded (hips-only) viewing conditions, with the latter two conditions emphasizing global and local information respectively. EEG was used to measure parietal alpha and beta oscillations. Skilled players outperformed less-skilled players, albeit both skill groups were less accurate under blurred and hips-only conditions. Skilled performers showed significant decreases in bilateral parietal beta power in the hips-only condition, suggesting a greater reliance on global information. Additionally, the hips-only condition evoked significantly greater beta relative to alpha power (beta – alpha) and lower overall alpha power than the control condition for both skill groups, suggesting this condition elicited a shift towards more local processing. Our novel findings demonstrate that skill and experience impact how motion is processed.

Keywords: EEG; parietal; sport; brain; beta; anticipation.

#### Introduction

Biological motion perception is influenced by viewing experience . When individuals observe point-light walking displays (PLDs), individuals are better at detecting walking direction, identity, and changes in speed for gait patterns resembling human motion compared to non-human or impossible gait patterns . Furthermore, younger infants prefer looking at PLDs that are non-biologically specific, developing a preference for human displays later in development . It is postulated that greater experience with a stimulus develops global processing ability, which entails holistic perception of multiple body segments . Novice observers may resort to more local processing, which entails detailed perception of individual body segments .

Skilled athletes learn to utilize distributed motion information across an opponent's body when anticipating actions such as throwing or kicking . In contrast, less-skilled athletes localize attention towards movement endpoints (e.g., arm-racquet for a tennis serve) . Skilled athletes potentially use a more global processing strategy, which may be advantageous when extracting motion information under severe time constraints. In contrast, less-skilled performers may resort to a local processing strategy based on a single reliable kinematic cue. Sport provides an effective vehicle to examine how skill impacts on motion processing during anticipation. In this study, we examine skill-related preferences for global and local motion information during a time-constrained sport task.

Hirai and colleagues proposed a two-process theory of biological motion perception of human walkers. The "Step-Detector" is biologically innate, pre-attentive, and necessitates local processing of the foot's motion and its spatial relationship to the rest of the body. The "Bodily Action Evaluator" (BAE) utilizes a global processing strategy, which is more dependent upon experience with the stimulus and mediated by local processing . Individuals use both processes when perceiving PLDs, but the BAE helps perceivers extract more complex visual information such as gender, facing direction, and emotion . Researchers have also demonstrated that individuals predominantly exhibit learning effects when observing coherent PLDs rather than scrambled, less-familiar PLDs . Coherent PLDs represent a stimulus most observers should have greater perceptual experience with, so individuals can utilize global processing of the BAE. Thus, learning effects for primarily coherent PLDs fit in with the framework of the BAE being a slower developing system reliant on perceptual experience .

Scientists have shown that less-skilled athletes focus on more localized motion cues . In observational learning studies using PLDs novices replicate movements better than experts on retention tests after training with endpoint displays compared to full body displays . While these studies do not focus on anticipation, they demonstrate that less-skilled individuals pick up motion information using a more local processing strategy during early stages of skill learning.

In assessing skill differences in motion processing, manipulating global and local motion features can help determine which information sources are primarily used. One way to manipulate global or local features is to remove low or high spatial frequency (LSF, HSF) information. LSF and HSF information in static images require global and local processing to detect, respectively. Attending to a *global* stimulus structure facilitates subsequent *LSF* processing, and attending to*local* stimulus components facilitates *HSF* processing . Thus, applying an LSF filter (i.e., "blurring" an image) should facilitate global motion processing while limiting local processing. That is, blur can degrade fine details for optimal local processing of single body segments and cause attention to be directed towards more salient global motion features. Blur-induced attentional modifications could subsequently allow individuals to globally process information from more body segments.

If visual blur encourages global processing of multiple body segments, then skilled observers, who may already inhibit local processing in favor of global processing, should be less affected by blur. Mann and colleagues showed that when anticipating the actions of cricket bowlers, skilled batters are generally unaffected by blur. Subsequently, scientists have reported that training using visual blur can improve performance. These authors propose that the dorsal visual pathway, specializing in motion and contrast perception, is predominantly used during action anticipation. Visual blur leaves primarily motion and contrast information intact while inhibiting irrelevant, fine-resolution information from the display.

The linkage between global processing and LSF information suggests that blurred displays emphasize global motion perception . Visual blur can reduce the quality of local motion information. Yet, skilled performers may already inhibit less-relevant local motion information because their experience enables them to use more global processing. Thus, visual blur effects may be redundant for skilled performers who process motion primarily using LSF information through global processing. In contrast, less-skilled individuals may instinctively use more localized information. Training under blur could direct attention to global motion characteristics and improve perception of holistic motion features. Very few researchers have compared how skilled and less-skilled observers perceive biological motion under visual blur . During motion perception under blur, there should be a greater shift from local to global processing. However, less-skilled individuals may not be as effective in using a global processing strategy due to their relative inexperience with global motion information in time-constrained tasks.

Traditionally, researchers have used HSF filters to contrast LSF (blurred) displays. Stimuli containing only HSF information retain a global movement structure though; all body segments are visible to maintain spatiotemporal organization of the movement. Spatial occlusion may be more functional for removing global motion information. Several researchers have implemented spatial occlusion paradigms, where specific body segments are occluded and replaced with the background or a black box. Causer and colleagues used spatial occlusion to isolate the hips during soccer penalty kicks. Only skilled goalkeepers could accurately predict

kicking direction from the hips, while less-skilled goalkeepers performed no better than chance. The hipsonly condition required individuals to focus on one body segment, which likely reinforced local processing. Skilled performers could still use local motion information with greater success, presumably due to more experience using the available information (i.e., hips).

The recording of neural measures can further elucidate whether global or local processing is being used. When examining brain activity during global/local perception, researchers have generally used static rather than the more dynamic images commonly employed in research on sport. However, perception of biological motion, like an image, depends upon the binding of local features into a global stimulus structure . Scientists have used PLDs where dots are replaced with different objects (e.g., stick figures, inverted faces), and perceivers are asked to discriminate walking direction. Perceivers are slower to determine walking direction when local stimuli contain information conflicting with the global structure (e.g., left-facing walker made up of smaller right-facing walkers) . These local interference effects are similar to what is reported in object recognition literature, where incongruent global and local stimulus structures can slow recognition of attended features . The posture-temporal filter model of biological motion perception asserts that neurons attuned to static postural forms during perception of PLDs are active when interpreting motion characteristics. Thus, the perception of motion and static images may be governed by similar neural networks to those responsible for detecting global and local stimulus features.

Given the conceptual overlap between global and local processing for different perceptual categories, a shared underlying cognitive construct for performance may exist on these tasks. Scientists using neural measures or lesion studies have demonstrated shared cognitive structures for global and local perception across perceptual tasks. Navon stimuli (e.g., larger letters made up of congruent or incongruent smaller letters) are typically used to assess the neural basis of global and local attention. Navon stimuli and other attentional tests show that temporo-parietal lesions in the right and left hemisphere impair global and local processing, respectively . Patients with left hemisphere lesions have trouble reproducing (drawing) local stimulus features and show a global advantage when viewing Navon stimuli, while those with right hemisphere lesions have trouble reproducing global stimulus features and show a local advantage when viewing Navon stimuli. In studies using EEG or fMRI with Navon stimuli, right and left temporo-parietal activation are associated with enhanced global and local processing respectively. Romei et al. showed that during a Navon task, rhythmic transcranial magnetic stimulation (TMS) in the alpha frequency range (8-13 Hz) impaired global processing when applied to the right parietal region, and impaired local processing when applied to the left parietal region. Alpha power is inversely related to cortical activation and reflects suppression of task-irrelevant brain regions for neural efficiency. Therefore, greater alpha activity can reduce the relative contribution of the left or right hemisphere for attentional processing. Spatial frequency processing is also reported to be hemispheric-specific, with LSFs processed in the right hemisphere and HSFs processed in the left hemisphere. In sum, there appears to be hemispheric specialization for global and local processing across different perceptual tasks which may include how biological motion is processed.

Lateralized alpha activity could indicate global or local attention during motion processing. Moreover, bilateral beta activity may facilitate local perception . Parietal beta activity is conjectured as functional for endogenously orienting top-down attention and evoking states of vigilance or alertness before local processing tasks. Beta activity oscillates at a higher frequency (14-30Hz), making it useful for detecting momentary changes in the environment with shorter and more frequent temporal processing windows. Furthermore, researchers have observed enhanced local perception when higher beta power is coupled with lower alpha power in posterior brain regions . Both alpha and beta power could indicate global or local processing dominance.

In this study, we determine skill-based differences in global and local processing using neural metrics and visual manipulations during anticipation of soccer penalty kicks. We used a video-based temporal occlusion paradigm with viewing conditions emphasizing global (visual blur) and local (spatial occlusion) motion information. We hypothesized that skilled players would outperform less-skilled players across conditions. Yet, we expected only less-skilled players to be negatively impacted by blur. We measured neural activity

during a preparatory period before motion processing because most of the work conducted in global-local processing looks at the preparatory period . However, since motion processing is a continuous task in which global and local visual attention can be continuously utilized, we also explored neural activity during the motion processing period. The following hypotheses apply to both processing periods. We expected less-skilled individuals to show a larger increase in left parietal alpha activity from the control to blurred (global) condition than skilled observers because the blurred condition should degrade their primarily-used local motion information . We expected skilled performers to show a larger increase in right parietal alpha from the control to hips-only condition because the hips-only condition should degrade their primarily used global motion information . We hypothesized that less-skilled observers would show greater beta – alpha power across viewing conditions and that greater beta – alpha power would be evident under spatial occlusion given its association with local processing . Finally, we expected parietal beta activity to be higher in less-skilled observers across all conditions irrespective of hemisphere because of previously established associations between bilateral beta power and local processing .

#### Methods

# Participants

We recruited 21 skilled (M age =  $29.8 \pm 8.5$ , 7 females) and 19 less-skilled (M age =  $28.2 \pm 5.0$ , 7 females) soccer players with normal or corrected-to-normal vision. Skilled players played in organized and semiprofessional leagues and had at least 10 years of competitive experience (23.3  $\pm$  9.6 years, play 1.9  $\pm$  1.4 times per week), whereas less-skilled players played infrequently and at the recreational level only (1.1  $\pm$ 1.2 years, play  $0.01 \pm 0.02$  times per week). Three participants reported having goalkeeper experience. A sensitivity analysis in G\*Power showed that 30-40 participants are sufficient to detect small-to-medium effect sizes (f = .20-.25) with 80% statistical power. This effect size range assumes a moderate correlation in brain activity across conditions for individuals (r = 0.60), which is reasonable given individual correlations in alpha asymmetry across tasks in other work. For EEG analyses, we removed three participants who were over 40 years of age because older populations have distinct neural activity in oscillatory frequencies from younger adults. We kept the three older participants in the behavioral performance analyses and removed one younger skilled participant due to corrupted performance measurements. There were three left-handed participants that we kept in our analyses since hemispheric-specific functions are likely not impacted by handedness. We include an analysis without left-handed participants in Appendix A. Participants received monetary compensation for their participation in the research. Informed consent was obtained for all participants, and ethical approval was granted by the University of Utah's Institutional Review Board (IRB). Additionally, individuals in experimental footage gave informed consent for publication of identifying images in an online open-access publication. All methods were performed in accordance with the Declaration of Helsinki.

#### Stimuli

We used  $\mathbf{v}$  ideo clips of soccer penalty kicks from the work of Causer and colleagues. These videos were recorded from the perspective of a goalkeeper standing in the center of the goal at eye height 1.7m off the ground. Videos consisted of penalty kicks from four full-time players at a professional club in England. Each player had three kicks at four possible targets (top left, bottom left, top right, or bottom right of the goal), making up a total of 48 video clips. The film clips included the player's approach to the ball and continued throughout the kicking action. Film was edited using Adobe Premiere Pro 2020 (Adobe Systems Incorporated, San Jose, CA). We applied Gaussian blur at 20 cycles per degree after piloting different blur intensities aimed at allowing skilled players to still perform above chance.

The spatially occluded footage was from Causer et al. and consisted of all body segments being replaced with the background except for the hips. We temporally occluded footage at 80ms before ball contact because this interval elicited scores between 61-72% accuracy for skilled players, and 39-50% accuracy for less-skilled players in the work by Causer et al. . The 80ms occlusion interval should have been challenging enough for both skill levels so the more skilled players would not experience a ceiling effect, and less-skilled players could score above chance. Finally, each video clip was preceded by a still frame of the clip's first frame

for 1000ms so we could record EEG during a preparatory period and compare the preparatory period to EEG recording during the videos. Each video clip was approximately 1400ms long. Stimuli (penalty kickers) moved towards the ball closer to the camera during each video clip, so the stimulus size was approximately 11.8-13.79cm, resulting in a visual angle of 10.87-12.69°. We used PsychoPy v2021.3 to present study stimuli. The computer monitor used was 53 x 32cm with a refresh rate of 60 Hz and pixel resolution of 1920 x 1080 pixels. The computer and monitor were stationed in the corner of a laboratory in which only the participant and experimenter were present. The computer was equipped with an Intel Core i7-7700K CPU, 32Gb of RAM, and an NVIDIA Quadro P4000 graphics card. Sample stimuli are displayed in Fig. 1.

#### Procedures

Participants filled out demographic questionnaires and were seated 62cm in front of the computer monitor. Participants were asked to avoid head and body movements throughout data acquisition to mitigate muscular and motion artifact in EEG signals. EEG data were collected during a 30-second baseline period with participants' eyes open staring at a blank monitor. A familiarization period was presented consisting of four video trials (2 normal, 1 blurred, and 1 occluded). Each trial consisted of a still image of the first video frame for 1000ms, the videos with temporal occlusion at 80ms before ball contact, and a black screen for 2000ms during which participants were told to make a keyboard response to guess the kick location. 'Enter' signified top right goal, 'right Ctrl' bottom right, 'Caps Lock' top left, and 'left Ctrl' bottom left. Feedback on performance was provided during familiarization but not during the study. The study consisted of 8 blocks of 34-35 trials (276 total) with normal, blurred, and spatially occluded clips randomly interleaved (92 trials of each condition). Participants had a 30-second break between blocks. The study in total took about 42 minutes to complete.

#### Measurements

Anticipation. Performance was measured by comparing predicted versus actual kick location. Performance was analyzed as the percentage (%) of trials answered correctly for kick direction, kick height, and combined kick direction and kick height (total).

Brain Activity. Brain activity was analyzed using BrainVision Recorder (Brain Products, GmbH, Munich, Germany). We used 32 channels in a 64-channel actiCAP system labeled in accordance with the international 10-20 system. Signals were amplified with a BrainAmp DC amplifier. The system collects data at 1000Hz, and impedances at each electrode were kept below  $25k\Omega$ . The ground electrode was placed on the right earlobe, and the reference electrode was placed directly anterior to Cz. We used frontotemporal (FT9, FT10) and temporoparietal (TP9, TP10) electrodes on the cap as vEOG and hEOG electrodes.

We resampled the data to 256 Hz, and an infinite impulse response (IIR) filter was applied with a high-pass filter at 0.1 Hz and a low-pass filter at 60 Hz (4<sup>th</sup> order). We used independent component analysis (ICA) with vEOG and hEOG to correct for ocular artifacts. We removed components that were influenced by ocular activity from the data (e.g., sum of squared correlations > 5). To enhance source localization, we transformed the data using surface Laplacian (SL). SL entails calculations subtracting the voltages from neighboring electrodes according to distance. We used a 4<sup>th</sup> order spline for SL due to its proven flexibility with lower density arrays. We manually inspected data for major muscular and blink artifacts which the ICA did not correct. Fast Fourier transformation (FFT) was applied to analyze oscillatory rhythms in the alpha (8-13Hz) and beta (14-30Hz) frequency ranges. Specifically, we examined activity at parietal electrodes (P3, P4, P7, P8) because this region participates in global and local perception as well as action observation. We averaged activity in the left (P3 and P7) and right (P4 and P8) hemisphere. Brain activity was measured at two epochs to assess a preparatory period (still image) in addition to the motion processing period because most global-local processing work uses preparatory periods to indicate subsequent processing mechanisms . Epoch 1 consisted of a 1-second baseline period with a still image of the first video frame, and Epoch 2 consisted of the video portion of the trial. We subtracted each participant's data from their 30-second baseline period.

#### **Data Analysis**

We conducted Shapiro-Wilk tests on dependent variables. Performance data were normally distributed (Direction: W = .982, p = .120; Height: W = .987, p = .316; Total: W = .980, p = .069). EEG data were log10 transformed to achieve a more normal distribution, but EEG data still violated assumptions of normality (Alpha: W = .856, p < .001; Beta: W = .937, p < .001). We used linear mixed effect regressions (LMERs) in our analyses given their robustness to violations of normally distributed data . LMERs also allow for the control of individual differences in intercepts within each condition, because otherwise, individual intercepts are treated as one combined mean, but random effects can control for individual responses to conditions . Thus, the ability of LMERs to account for random effects while maintaining a general robustness to violations of normality allows for more accurate statistical estimates compared to non-parametric tests. We created a variable to assess relative differences between beta and alpha power (beta power minus alpha power, or beta – alpha) because higher beta power accompanied by lower alpha power has been associated with local processing dominance . The LMER assessing anticipation performance (% correct) included factors of Skill (skilled, less-skilled) and Condition (normal, blur, occlusion), interaction terms, and random effects for Participant:

# Performance ~ Skill \* Condition + (1|Participant)

LMERs for each EEG variable (alpha power, beta power, beta – alpha power) included factors of Skill (skilled, less-skilled), Hemisphere (right, left), Condition (normal, blur, occlusion), interaction terms, and random effects of Participant and Participant crossed with Condition and Hemisphere:

We used separate models to analyze data in each epoch. For mixed models, we calculated effect sizes as partial eta-squared ( $\eta^2$ ) values, and confidence intervals (*CI*) are reported for  $\eta^2$  values. We reported model performance as the marginal  $R^2$  values for LMERs which provides the variance explained by fixed effects of the model. Post hoc follow-up tests were conducted using contrast analyses with Benjamini-Hochberg corrections for multiple testing, and we report Cohen's *d* effect sizes. In communicating our EEG results, we first address the preparatory period (epoch 1) then the motion processing period (epoch 2) for each dependent variable. We place statistical results testing our main hypotheses at the beginning of each section, and subsequent results exploring other outcomes are reported afterwards. Data analyses were conducted using R Studio v2022.7.1.

#### Results

#### **Anticipation Performance**

Direction . There were significant main effects of Skill  $(p < .001, \eta^2 = .141)$  and Condition  $(p < .001, \eta^2 = .397)$ , which were superseded by an interaction between Skill and Condition  $(p = .018, \eta^2 = .083)$ . Skilled players performed significantly better than less-skilled players in the normal (p < .001, d = .50) and blurred conditions (p = .009, d = .33), but not in the hips-only condition, (p = .205, d = .15). For both skill groups, performance was significantly worse in the hips-only condition compared to the control (p 's < .011, d 's > .33) and blurred conditions (p 's < .011, d 's > .34).

*Height*. There was a significant main effect of Condition,  $(p < .001, \eta^2 = .176)$ . Performance was significantly worse in the hips-only compared to the normal (p < .001, d = .48) and blurred conditions (p = .001, d = .41), but no difference emerged between the control and blurred condition (p = .543, d = .07). Importantly though, performance was not significantly above chance level when anticipating height in the blurred (p = .145) and hips-only conditions (p = .999). Thus, comparisons between the blurred and hips-only condition should be interpreted with caution. There was no main effect for Skill  $(p = .705, \eta^2 = .001)$  or interaction between Condition and Skill  $(p = .153, \eta^2 = .035)$ .

Total. There were significant main effects of Skill  $(p = .011, \eta^2 = .067)$  and Condition  $(p < .001, \eta^2 = .391)$ . Skilled players performed significantly better than less-skilled players across conditions (p = .013, d = .29). Both skill groups performed superiorly in the control condition compared to the blurred (p = .29).

.013, d = .30) and hips-only condition (p < .001, d = .91). Additionally, participants were more accurate in the blurred condition compared to the hips-only condition (p < .001, d = .60). No significant interaction emerged between Skill and Condition (p = .011,  $\eta^2 = .067$ ). Performance data are depicted in Fig. 2, and detailed statistical outputs for performance data can be found in Table 1 and Table 2.

#### **Brain Activity**

Alpha Power Epoch 1. We hypothesized that skilled players would show greater parietal alpha power in the left hemisphere according to viewing conditions during the preparatory period, but no interaction emerged between Skill, Condition, and Hemisphere,  $(p = .303, \eta^2 = .031)$ . We also found no support for hemispheric lateralization according to skill level as no interaction was evident between Skill and Hemisphere  $(p = .621, \eta^2 = .003)$ . We tested whether viewing conditions would impact brain activity differently according to skill, but no interaction was evident between Skill and Condition  $(p = .726, \eta^2 = .008)$ . Other main effects and interactions did not reach significance  $(p \ s > .090)$ .

Alpha Power Epoch 2 . We expected skilled players would show greater parietal alpha power in the left hemisphere according to viewing conditions during motion processing, but no interaction emerged between Skill, Condition, and Hemisphere,  $(p = .390, \eta^2 = .023)$ . Further, there was no support for hemispheric lateralization according to skill level as no interaction was evident between Skill and Hemisphere  $(p = .691, \eta^2 = .002)$ . We tested whether viewing conditions would impact brain activity differently according to skill, but no interaction was evident between Skill and Condition  $(p = .066, \eta^2 = .066)$ . Viewing conditions did impact brain activity though, as there was a main effect of Condition  $(p < .001, \eta^2 = .299)$  (Fig. 3). The hips-only condition evoked significantly less alpha power than the control (p < .001, d = .65), and blurred condition (p = .084, d = .20). Other main effects and interactions did not reach significance (p 's > .343).

Beta Power Epoch 1. We expected skilled players would show reduced parietal beta power compared to less-skilled players during the preparatory period, but no significant main effect was observed for Skill (p = .094,  $\eta^2 = .038$ ). Other effects and interactions failed to reach significance (p 's > .107).

Beta Power Epoch 2. We hypothesized that skilled players would show reduced parietal beta power compared to less-skilled players during motion processing. There was no main effect for Skill,  $(p = .306, \eta^2 = .014)$ . However, there was a significant main effect of Condition  $(p < .001, \eta^2 = .215)$ , which was superseded by a significant interaction between Skill and Condition  $(p = .022, \eta^2 = .094)$  (Fig. 3). For only skilled performers, there was lower beta power in the hips-only condition compared to the control (p < .001, d = .54), and blurred condition (p < .001, d = .48), but no differences emerged between the control and blurred condition (p = .651, d = .06). Other main effects and interactions did not reach significance (p 's > .248).

Beta – Alpha Power Epoch 1. We hypothesized that skill level and viewing conditions would impact beta – alpha power during the preparatory period. There was no main effect of Skill  $(p = .725, \eta^2 = .001)$  or Condition  $(p = .790, \eta^2 = .005)$ . However, there was a significant interaction between Condition and Hemisphere  $(p = .032, \eta^2 = .073)$  and between Skill, Condition, and Hemisphere  $(p = .038, \eta^2 = .070)$ . However, post hoc tests did not reveal any significant differences after correcting for multiple comparisons, indicating that p-value corrections eliminated type I error (see Appendix B for post hoc results). Other main effects and interactions did not reach significance  $(p \ s > .105)$ .

Beta – Alpha Power Epoch 2 . In testing whether greater beta – alpha power would be associated with less-skilled motion perception, we did not find a main effect of Skill ( $p = .224, \eta^2 = .017$ ). We also expected beta – alpha power to be impacted by viewing condition, and we found a significant main effect for Condition ( $p = .001, \eta^2 = .155$ ) (Fig. 3). The hips-only condition produced significantly greater beta – alpha power than the control condition (p < .001, d = .46), but no difference emerged between control and blur (p = .075, d = .21), or between blur and hips-only (p = .075, d = .25). Other main effects and interactions did not reach significance (p 's > .100). Detailed statistical outputs for EEG data can be found in Table 3 and Table 4.

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#### Discussion

We examined skill-related differences in motion processing during anticipation using a penalty kick task with visual conditions that manipulated access to global and local motion information. We expected skilled players to outperform less-skilled players across conditions, and that only less-skilled players would be adversely affected by visual blur. We hypothesized that skilled players would generally show greater alpha power in the left parietal region and less bilateral beta power than less-skilled players particularly in the blurred condition, evidencing more global processing, while less-skilled players would show the opposite trend. We also expected less skilled players to show greater bilateral beta – alpha power than skilled players which would evidence more local processing. Finally, we expected skilled players to be more influenced by the hips-only condition and less-skilled players to be more influenced by visual blur.

Skilled players outperformed less-skilled players across conditions in anticipating kick direction and combined kick direction and height, and performance declined from the control to blurred to hips-only conditions for both skill groups (control > blur > hips-only). In accordance with our hypothesis, neural findings showed an effect of viewing condition on motion processing for both skill groups. The hips-only condition evoked significantly lower bilateral alpha power and greater bilateral beta – alpha power which are both neural markers of enhanced local processing. We found no support for our hypothesis that less skilled players would show greater beta power than skilled players. However, for skilled performers, the hips-only condition elicited *lower* bilateral beta power than the control and blurred condition during motion processing suggesting that skilled motion processing was altered by removing global motion information. Overall, the neural results mostly did not support our hypothesized outcomes related to skill and hemispheric lateralization, but other findings showed that skilled observers may be more reliant upon global motion information than less-skilled observers.

The role of beta power during cognitive processing has been investigated and contested in numerous contexts including motor preparation , visual alertness , cortical inhibition , and local stimulus processing . However, beta power has not been studied on tasks involving global and local biological motion processing. Beta power is associated with "maintaining the status quo," or regulating top-down attention in anticipation of an expected stimulus outcome . In this framework, beta power desynchronization reflects reduced contributions from top-down attentional networks to facilitate processing of exogenous information when outcomes are less certain . Moreover, alpha power reductions facilitate exogenous information processing by releasing inhibition of cortical regions . Our neural results fit with these latter conjectures because during the motion processing period, alpha and beta power were both reduced under spatial occlusion which participants were least familiar. Participants should be most familiar with conditions containing both global and local motion information, but the removal of global information under spatial occlusion likely caused a shift away from top-down neural networks to track the evolving dynamics of the isolated hip movement . These neural shifts likely contributed to performance decrements in the hips-only condition. Thus, decreases in alpha power suggest that degraded global motion information caused some uncertainty and enhanced bottom-up processing .

Only skilled performers showed significantly lower beta power in the hips-only condition compared to blur and control conditions. Skilled players use kinematic information distributed across an opponent's entire body for accurate anticipation, suggesting that they may be better at globally processing movement. Less beta power could signal a processing shift through greater parietal activation. Furthermore, the neural results suggest spatial occlusion elicited more local processing through greater bilateral beta – alpha power across skill groups. High beta with low alpha power has been associated with heightened vigilance and local processing for an upcoming stimulus. Thus, the hips-only condition may have demanded more local processing which disrupted global processing in skilled performers. Less-skilled performers did not show significant beta power decreases in the hips-only condition, so the way they processed motion for anticipation may not have been as disrupted by removing global information as skilled performers.

We expected left hemispheric lateralization of alpha power to be evident in skilled players to indicate global processing dominance, but our findings did not support a particular role for left or right parietal specialization

during motion processing. Previous reports showing hemispheric specialization for global and local processing may be specific to the static stimuli employed (i.e., Navon letters). Given the conceptual overlap between global and local processing for different perceptual categories (e.g., biological motion, objects), it is logical to presume a shared underlying cognitive construct for performance on these tasks. However, some researchers have refuted this idea . Behavioral performance on different perceptual tasks has been compared (e.g., Navon letters, face discrimination), and generally no relationships are found for performance between tasks . These findings indicate that global and local processing biases may be very task specific, which fits in with the framework that experience with a stimulus will modulate perceptual strategies. Notably, researchers who have compared global and local processing across tasks have used behavioral measures, so our investigation is the first to assess perception of different stimulus categories with neural data. The lack of hemispheric specialization in our results suggests that global and local motion processing may involve different neural pathways and activation than what has previously been observed in studies using static images. Cortical activity may exhibit more rapid changes in dynamic real-world tasks. More work is needed to thoroughly assess neural networks involved in global and local motion processing.

It is perhaps noteworthy that significant neural findings were only evident during the motion processing period (epoch 2) rather than during the preparatory period. Previous investigations looking at neural correlates of global and local processing have predominantly assessed alpha and beta power immediately before stimulus presentation. Given the absence of significant results during the preparatory period in the present study, it is possible that global and local processing of movement depends on observation of the movement itself. For instance, perception of walking direction in point light display studies is contingent upon the motion of the stimulus to determine how individual points are moving in relation to one another . With this reasoning, skill and condition differences in neural activity would arise primarily during the period where motion is being observed, so individuals can attend to global or local features of the movement. Furthermore, preparatory periods in other studies typically entail a fixation cross , and studies using event-related potentials in response to a spatial frequency stimulus typically involve a behavioral task associated with interpreting the static image . Our preparatory period did not have an associated behavioral task, which may have resulted in more passive stimulus observation while waiting for the stimulus to begin moving. In future, researchers should take into consideration task demands when presenting global and local motion stimuli.

Investigations using visual blur during anticipation have generally not compared performance outcomes between skilled and less-skilled athletes, with previous work only highlighting that experts are largely resilient to blur . Our findings corroborate the notion that skilled athletes are better at anticipating under blur than less-skilled athletes , but blur had a negative impact on anticipation of combined kick height and direction in both skill groups. Ryu and colleagues compared skilled and less-skilled individuals in a basketball decisionmaking task under visual blur. Performance was preserved under mild to moderate blur in skilled players, whereas performance suffered depending on the location of blur (central or peripheral vision) in less-skilled individuals . The task used by Ryu et al. is markedly different from our soccer task; Ryu's study featured third-person video footage and required tracking player positions, while our study entailed observing a single opponent's movements in first-person. Thus, our results present novel comparisons between skill levels, showing that both skill groups likely rely on some local information for accurate anticipation which blur degrades.

Skill differences in performance were primarily evident when predicting kick lateral direction rather than kick height. Further, participants did not perform above chance level when anticipating kick height in blurred and hips-only conditions. Previous reports have suggested that early ball flight information is necessary to anticipate kick height, so temporal occlusion intervals preceding ball-contact will likely not elicit skill differences in height anticipation. Furthermore, given our skilled sample predominantly consisted of athletes who did *not* play goalkeeper, it is sensible that anticipation of kick direction is more readily picked up. Soccer players in other positions must extract motion information from the ball-carrier to predict which direction they will go with a pass, and kick height may not be a critical factor to anticipate in such scenarios.

Limited work has made explicit conjectures about the role of beta oscillations during biological motion processing. Denis and colleagues looked at sensorimotor oscillations in the alpha and beta frequency bands during a tennis anticipation task. Significant beta power reductions were found only for skilled observers in sensorimotor regions but not parietal regions. The authors suggested that beta desynchronization in sensorimotor regions of skilled players reflects greater certainty about action outcomes during motor preparation. In contrast, we observed skill-related *parietal* beta reductions in more difficult visual conditions, suggesting that the role of beta power is likely task-specific, skill-dependent, and serves different functions according to brain region. Furthermore, most of the work measuring beta and alpha oscillations for global/local processing assess these neural correlates in preparation for a stimulus or during a very short time interval following stimulus presentation rather than during continuous stimulus processing. We chose to measure neural activity during both a preparatory and stimulus processing period to gain a fuller understanding of how skill impacts alpha and beta power *during* motion processing. Finally, it is possible that the skilled group would have demonstrated more distinct behavioral and neural results from the less-skilled group if all skilled players were goalkeepers. Supporting this notion, behavioral results from the work by Causer and colleagues using the same footage produced larger performance differences between skill-levels with a skilled sample of purely goalkeepers. However, Causer's task was not computer-based (participants physically moved to respond), and their study had significantly less trials than our study (96 trials versus 276). Nevertheless, the skilled group still demonstrated superior performance to the less-skilled group which demonstrates that their perceptual experience acquired in other playing positions contributed to their ability to accurately anticipate the movements of penalty kickers.

### 5. Conclusions

Scientists have conjectured that experience facilitates global processing, and our findings lend support to this notion . Skilled soccer players, who possess more observational experience with soccer-related actions, anticipate penalty kicks better than less-skilled players, even when local motion information is degraded. Skilled performers' neural activity during motion processing is particularly disrupted when global motion information is removed, suggesting that they predominantly use global processing. However, our results did not align neatly with commonly used brain correlates of global or local attention, and our discussion primarily draws upon inferences from visual condition effects. Further investigation is necessary to elucidate skill-related mechanisms of motion processing. Given that beta power has been much less investigated than alpha power alongside attention, this study provides groundwork for researchers to investigate parietal alpha-beta power relationships when viewing more ecologically valid motion stimuli.

#### References

Dependent Variable	Fixe
Direction	Skil
	Con
	$\operatorname{Skil}$
Height	Skil
	Con
	Skil
Total	$\operatorname{Skil}$
	Con
	Skil
Table 1: Mixed model results for analyses on performance measurements. Significant results are highlighted in <b>bol</b>	d. Tab

Direction

Dependent Variable

Height

Total

Table 2: Post hoc comparisons for performance models. "Effect/Interaction" refers to the significant main effect or interaction

# Dependent Variable

Alpha Power

Beta Power

Beta – Alpha Power

Table 3: Mixed model results for analyses on EEG measu	rements. Significant results are highlighted in <b>bold.</b> *I	Post hoc a
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Dependent	Effect /	Factor	Post hoc	0	(TE		1	
Variable	Interaction	Levels	comparison	β	SE	p	d	
Alpha Power	Condition		Control [?] Blur	.029	.017	.084	.20	
Epoch 2			[•] Diai					
Lpoon 2			Control >	.093	.017	<.001	.65	
			Hips-only			• • •		
			Blur >	.063	.017	< .001	.44	
			Hips-only					
Beta	Skill x	Control	Skilled [?]	.153	.136	.451	.13	
Power	Condition		Less					
Epoch 2			Skilled					
		Blur	Skilled [?]	.165	.136	.451	.14	
			Less					
			Skilled					
		Hips-only	Skilled [?]	.088	.136	.651	.08	
			Less					
		01.11.1	Skilled	010	000	051	0.0	
		Skilled	Control [2] Dlum	.010	.022	160.	.06	
			[:] Diur Control >	007	022	< 001	54	
			Hips-only	.097	.022	<.001	.04	
			Blur >	087	022	<.001	48	
			Hips-only		.022	(1001	.10	
		Less	Control	.022	.021	.451	.12	
		Skilled	[?] Blur					
			Control	.032	.021	.651	.17	
			[?]					
			Hips-only					
			Blur [?]	.010	.021	.416	.05	
			Hips-only					
Beta –	Condition		Control [?]	.013	.007	.075	.21	
Alpha Power			Blur					
Epoch 2				000	007	. 001	10	
			Control < U	.028	.007	<.001	.46	
			Hips-only					

Dependent Variable	Effect / Interaction	Factor Levels	Post hoc comparison	β	SE	p	d	
			Blur [?] Hips-only	.015	.007	.075	.25	

Dependent Variable	Effect / Interaction	Factor Levels	Post hoc comparison	β	SE	p	d
Table 4:	Table 4:	Table 4:	Table 4:	Table 4:	Table 4:	Table 4:	Table 4:
Post hoc	Post hoc	Post hoc	Post hoc	Post hoc	Post hoc	Post hoc	Post hoc
compar-	compar-	compar-	compar-	compar-	compar-	compar-	compar-
isons for	isons for	isons for	isons for	isons for	isons for	isons for	isons for
EEG	EEG	EEG	EEG	EEG	EEG	EEG	EEG
mixed	mixed	mixed	mixed	mixed	mixed	mixed	mixed
models.	models.	models.	models.	models.	models.	models.	models.
"Ef-	"Ef-	"Ef-	"Ef-	"Ef-	"Ef-	"Ef-	"Ef-
fect/Interacti	onfect/Interacti	ionfect/Interacti	ionfect/Interacti	onfect/Interacti	ionfect/Interact	ionfect/Interact	ionfect/Interactio
refers to	refers to	refers to	refers to	refers to	refers to	refers to	refers to
the	the	the	the	the	the	the	the
significant	significant	significant	significant	significant	significant	significant	significant
main	main	main	main	main	main	main	main
effect or	effect or	effect or	effect or	effect or	effect or	effect or	effect or
interaction	interaction	interaction	interaction	interaction	interaction	interaction	interaction
found in	found in	found in	found in	found in	found in	found in	found in
the mixed	the mixed	the mixed	the mixed	the mixed	the mixed	the mixed	the mixed
model.	model.	model.	model.	model.	model.	model.	model.
"Factor	"Factor	"Factor	"Factor	"Factor	"Factor	"Factor	"Factor
Levels"	Levels"	Levels"	Levels"	Levels"	Levels"	Levels"	Levels"
refers to	refers to	refers to	refers to	refers to	refers to	refers to	refers to
levels	levels	levels	levels	levels	levels	levels	levels
within a	within a	within a	within a	within a	within a	within a	within a
factor in	factor in	factor in	factor in	factor in	factor in	factor in	factor in
which post	which post	which post	which post	which post	which post	which post	which post
hoc com-	hoc com-	hoc com-	hoc com-	hoc com-	hoc com-	hoc com-	hoc com-
parisons	parisons	parisons	parisons	parisons	parisons	parisons	parisons
are being	are being	are being	are being	are being	are being	are being	are being
made for	made for	made for	made for	made for	made for	made for	made for
interac-	interac-	interac-	interac-	interac-	interac-	interac-	interac-
tions. " $\beta$ "	tions. " $\beta$ "	tions. " $\beta$ "	tions. " $\beta$ "	tions. " $\beta$ "	tions. " $\beta$ "	tions. " $\beta$ "	tions. " $\beta$ "
refers to	refers to	refers to	refers to	refers to	refers to	refers to	refers to
the	the	the	the	the	the	the	the
estimated	estimated	estimated	estimated	estimated	estimated	estimated	estimated
difference	difference	difference	difference	difference	difference	difference	difference
between	between	between	between	between	between	between	between
compared	compared	compared	compared	compared	compared	compared	compared
groups.	groups.	groups.	groups.	groups.	groups.	groups.	groups.
"[?]"	"[?]"	"[?]"	"[?]"	"[?]"	"[?]"	"[?]"	"[?]"
denotes	denotes	denotes	denotes	denotes	denotes	denotes	denotes
nonsignifi-	nonsignifi-	nonsignifi-	nonsignifi-	nonsignifi-	nonsignifi-	nonsignifi-	nonsignifi-
cant	cant	$\operatorname{cant}$	$\operatorname{cant}$	$\operatorname{cant}$	cant	cant	cant
difference.	difference.	difference.	difference.	difference.	difference.	difference.	difference.
Effect	Effect	Effect	Effect	Effect	Effect	Effect	Effect
sizes are	sizes are	sizes are	sizes are	sizes are	sizes are	sizes are	sizes are
displayed	displayed	displayed	displayed	displayed	displayed	displayed	displayed
as Cohen's	as Cohen's	as Cohen's	as Cohen's	as Cohen's	as Cohen's	as Cohen's	as Cohen's
d.	d.	d.	d.	d.	d.	d.	d.
Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant
results are	results are	results are	results are	results are	results are	results are	results are
high-	high-	high-	high-	high-	high-	high-	high-
lighted in	lighted in	lighted in	lighted 5in	lighted in	lighted in	lighted in	lighted in
bold.	bold.	bold.	bold.	bold.	bold.	bold.	bold.

Dependent	Effect /	Factor	Post hoc				
Variable	Interaction	Levels	comparison	β	SE	p	d



**Fig. 1**. **Top**: Video stimuli used in the experiment. **A**) Normal condition (normal), **B**) Blurred condition (blur), and **C**) Spatially occluded condition (hips-only). **Bottom**: Schematic of trials. At the start of each trial, participants viewed a still-image of the video's first frame for 1000ms, then they watched the video of the penalty kick. Following the kick, a blank screen was presented for 2000ms during which participants had to use the keyboard to predict where the ball would end up.

# [CHART][CHART][CHART]

Fig. 2. Performance accuracy scores for normal, blurred, and hips-only conditions (in %). Grey dashed lines represent chance level performance. Skilled players anticipated direction significantly better than less-skilled players in the normal and blurred conditions. No skill differences were evident for anticipation of height. Skilled players anticipated combined direction and height (total) better than less-skilled players across all conditions. For both skill groups, performance was significantly worse in the hips-only compared to the normal and blurred condition for each performance measurement. Anticipation of height was not greater than chance level for the blurred and hips-only viewing conditions.





Condition



**Beta Power** 

Condition



**Fig. 3**. Log-transformed parietal beta and alpha power for each visual condition and skill group. Negative values reflect desynchronization from a baseline period. Individual data points and lines represent each subject's change between conditions. **Top Left** ) Both skill groups showed significantly lower alpha power in the hips-only compared to control and blurred condition. **Top Right** ) Only skilled performers showed significant reductions in beta power in the hips-only compared to control and blurred condition. **Top Right** ) Only skilled performers showed significant reductions in beta power in the hips-only compared to control and blurred conditions. **Bottom** ) Both skill groups had higher beta relative to alpha power (beta – alpha power) in the hips-only compared to the control condition. \* denotes p < .05, \*\* denotes p < .01, and \*\*\* denotes p < .001. There were no skill interactions for alpha power and beta – alpha power plots, meaning that comparisons are averaged across groups in these plots and replicated in both skill boxes for uniformity.

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