
Reach-to-grasp movements change quantitatively in a lawful (i.e. predictable) manner with changes in object properties. We explored whether altering object texture would produce qualitative changes in the form of the precontact movement patterns. Twelve participants reached to lift objects from a tabletop. Nine objects were produced, each with one of three grip surface textures (high-friction, medium-friction and low-friction) and one of three widths (50 mm, 70 mm and 90 mm). Each object was placed at three distances (100 mm, 300 mm and 500 mm), representing a total of 27 trial conditions. We observed two distinct movement patterns across all trials-participants either: (i) brought their arm to a stop, secured the object and lifted it from the tabletop; or (ii) grasped the object ‘on-the-fly’, so it was secured in the hand while the arm was moving. A majority of grasps were on-the-fly when the texture was high-friction and none when the object was low-friction, with medium-friction producing an intermediate proportion. Previous research has shown that the probability of on-the-fly behaviour is a function of grasp surface accuracy constraints. A finger friction rig was used to calculate the coefficients of friction for the objects and these calculations showed that the area available for a stable grasp (the ‘functional grasp surface size’) increased with surface friction coefficient. Thus, knowledge of functional grasp surface size is required to predict the probability of observing a given qualitative form of grasping in human prehensile behaviour.


Following many studies showing that the coupling in bimanual coordination can be perceptual, Bingham (Ecol Psychol in 16:45-53, 2001; 2004a, b) proposed a dynamical model of such movements. The model contains three key hypotheses: (1) Being able to produce stable coordinative movements is a function of the ability to perceive relative phase, (2) the information to perceive relative phase is relative direction of motion, and (3) the ability to resolve this information is conditioned by relative speed. The first two hypotheses have been well supported (Wilson and Bingham in Percept Psychophys 70:465-476, 2008; Wilson et al. in JExp Psychol Hum 36:1508-1514, 2010a), but the third was not supported when tested by de Rugy et al. (Exp Brain Res 184:269-273, 2008) using a visual coordination task that required simultaneous control of both the amplitude and relative phase of movement. The purposes of the current study were to replicate this task with additional measures and to modify the original model to apply it to the new task. To do this, we conducted two experiments. First, we tested the ability to produce 180° visual coordination at different frequencies to determine frequencies suitable for testing in the de Rugy et al. task. Second, we tested the de Rugy et al. task but included additional measures that yielded results different from those reported by de Rugy et al. These results were used to elaborate the original model. First, one of the
phase-driven oscillators was replaced with a harmonic oscillator, so the resulting coupling was unidirectional. This change resulted in the model producing less stable 180° coordination behavior beyond 1.5 Hz consistent with the results obtained in Experiment 1. Next, amplitude control and phase correction elements were added to the model. With these changes, the model reproduced behaviors observed in Experiment 2. The central finding was that the stability of rhythmic movement coordination does depend on relative speed and, thus, all three of the hypotheses contained in the original Bingham model are supported.


Locomoting-to-reach is a basic perception/action behavior that requires visual information for the control of both locomotion and reaching components. We investigated the visual information and the control strategies used to guide both the head and the hand on approach to a target in a locomotion-to-reach task. In this study, participants were required to locomote in the dark to a lit target in three different conditions: monocular vision/target with image size, binocular vision/target with image size, and binocular vision/point-light target (without image size). In task one, participants brought their eyes to the target. In task two, participants brought their outstretched hand to the target. Movement trajectories for both tasks were analyzed. Results show that participants were significantly more accurate when binocular information was present. In both tasks, participants were found to use a proportional rate control strategy rather than a constant \( \tau \) strategy. In the walk-to-reach task, they used monocular and/or binocular \( \tau \) information to guide the head and then switched to using relative disparity \( \tau \) to guide the hand to final target acquisition, switching when the hand centric \( \tau \) became less than the head centric \( \tau \). Dynamical models of the information and control strategies were used to perform simulations that were found to fit the data well. The conclusion is that proportional rate control is used sequentially with head centric, then hand-centric \( \tau \)-based information, using at each moment the \( \tau \) with the smallest value.


Extensive research has identified the affordances used to guide actions, as originally conceived by Gibson (Perceiving, acting, and knowing: towards an ecological psychology. Erlbaum, Hillsdale, 1977; The ecological approach to visual perception. Erlbaum, Hillsdale, 1979/1986). We sought to discover the object affordance properties that determine the spatial structure of reach-to-grasp movements--movements that entail both collision avoidance and targeting. First, we constructed objects that presented a significant collision hazard and varied properties relevant to targeting, namely, object width and size of contact surface. Participants reached-to-grasp objects at three speeds (slow, normal, and fast). In Experiment 1, we explored a "stop" task
where participants grasped the objects without moving them. In Experiment 2, we studied "fly-through" movements where the objects were lifted. We discovered the object affordance properties that produced covariance in the spatial structure of reaches-to-grasp. Maximum grasp aperture (MGA) reflected affordances determined by collision avoidance. Terminal grasp aperture (TGA)--when the hand stops moving but prior to finger contact--reflected affordances relevant to targeting accuracy. A model with a single free parameter predicted the prehensile spatial structure and provided a functional affordance-based account of that structure. In Experiment 3, we investigated a "slam" task where participants reached-to-grasp flat rectangular objects on a tabletop. The affordance structure of this task was found to eliminate the collision risk and thus reduced safety margins in MGA and TGA to zero for larger objects. The results emphasize the role of affordances in determining the structure and scaling of reach-to-grasp actions. Finally, we report evidence supporting the opposition vector as an appropriate unit of analysis in the study of grasping and a unit of action that maps directly to affordance properties.

5. Wilson AD, Snapp-Childs W, Bingham GP. Perceptual learning immediately yields new stable motor coordination. J Exp Psychol Hum Percept Perform. 2010 Dec;36(6):1508-14. Centre for Sport & Exercise Science, Institute of Membrane and Systems Biology, University of Leeds, Leeds, UK. A.D.Wilson@leeds.ac.uk PMID: 20731515 [PubMed - indexed for MEDLINE] Coordinated rhythmic movement is specifically structured in humans. Movement at 0° mean relative phase is maximally stable, 180° is less stable, and other coordinations can, but must, be learned. Variations in perceptual ability play a key role in determining the observed stabilities so we investigated whether stable movements can be acquired by improving perceptual ability. We assessed movement stability in Baseline, Post Training, and Retention sessions by having participants use a joystick to coordinate the movement of two dots on a screen at three relative phases. Perceptual ability was also assessed using a two-alternative forced choice task in which participants identified a target phase of 90° in a pair of displays. Participants then trained with progressively harder perceptual discriminations around 90° with feedback. Improved perceptual discrimination of 90° led to improved performance in the movement task at 90° with no training in the movement task. The improvement persisted until Retention without further exposure to either task. A control group's movement stability did not improve. Movement stability is a function of perceptual ability, and information is an integral part of the organization of this dynamical system.

6. Wilson AD, Snapp-Childs W, Coats R, Bingham GP. Learning a coordinated rhythmic movement with task-appropriate coordination feedback. Exp Brain Res. 2010 Sep;205(4):513-20. Epub 2010 Aug 12. Centre for Sport and Exercise Sciences, Institute of Membrane and Systems Biology, University of Leeds, Leeds, LS2 9JT, UK. A.D.Wilson@leeds.ac.uk PMID: 20703872 [PubMed - indexed for MEDLINE] A common perception-action learning task is to teach participants to produce a novel coordinated rhythmic movement, e.g. 90 degrees mean relative phase. As a general rule, people cannot produce these novel movements stably without training. This is
because they are extremely poor at discriminating the perceptual information required to coordinate and control the movement, which means people require additional (augmented) feedback to learn the novel task. Extant methods (e.g. visual metronomes, Lissajous figures) work, but all involve transforming the perceptual information about the task and thus altering the perception-action task dynamic being studied. We describe and test a new method for providing online augmented coordination feedback using a neutral colour cue. This does not alter the perceptual information or the overall task dynamic, and an experiment confirms that (a) feedback is required for learning a novel coordination and (b) the new feedback method provides the necessary assistance. This task-appropriate augmented feedback therefore allows us to study the process of learning while preserving the perceptual information that constitutes a key part of the task dynamic being studied. This method is inspired by and supports a fully perception-action approach to coordinated rhythmic movement.


Bingham, Schmidt, & Rosenblum, (1989) showed that people are able to select, by hefting balls, the optimal weight for each size ball to be thrown farthest. We now investigate function learning and smart mechanisms as hypotheses about how this affordance is perceived. Twenty-four unskilled adult throwers learned to throw by practicing with a subset of balls that would only allow acquisition of the ability to perceive the affordance if hefting acts as a smart mechanism to provide access to a single information variable that specifies the affordance. Participants hefted 48 balls of different sizes and weights and judged throwability. Then, participants, assigned to one of four groups, practiced throwing (three groups with vision and one without) for a month using different subsets of balls. Finally, hefting and throwing were tested again with all the balls. The results showed: (1) inability to detect throwability before practice, (2) throwing improved with practice, and (3) participants learned to perceive the affordance, but only with visual feedback. These results indicated that the affordance is perceived using a smart mechanism acquired while learning to throw.


We provide a solution to a major problem in visually guided reaching. Research has shown that binocular vision plays an important role in the online visual guidance of reaching, but the visual information and strategy used to guide a reach remains unknown. We propose a new theory of visual guidance of reaching including a new information variable, tau(alpha) (relative disparity tau), and a novel control strategy that
allows actors to guide their reach trajectories visually by maintaining a constant proportion between tau(alpha) and its rate of change. The dynamical model couples the information to the reaching movement to generate trajectories characteristic of human reaching. We tested the theory in two experiments in which participants reached under conditions of darkness to guide a visible point either on a sliding apparatus or on their finger to a point-light target in depth. Slider apparatus controlled for a simple mapping from visual to proprioceptive space. When reaching with their finger, participants were forced, by perturbation of visual information used for feedforward control, to use online control with only binocular disparity-based information for guidance. Statistical analyses of trajectories strongly supported the theory. Simulations of the model were compared statistically to actual reaching trajectories. The results supported the theory, showing that tau(alpha) provides a source of information for the control of visually guided reaching and that participants use this information in a proportional rate control strategy.


Lee et al. (Percept Psychophys 70:1032-1046, 2008a) investigated whether visual perception of metric shape could be calibrated when used to guide feedforward reaches-to-grasp. It could not. Seated participants viewed target objects (elliptical cylinders) in normal lighting using stereo vision and free head movements that allowed small (approximately 10 degrees) perspective changes. The authors concluded that poor perception of metric shape was the reason reaches-to-grasp should be visually guided online. However, Bingham and Lind (Percept Psychophys 70:524-540, 2008) showed that large perspective changes (> or =45 degrees) yield good perception of metric shape. So, now we repeated the Lee et al.’s study with the addition of information from large perspective changes. The results were accurate feedforward reaches-to-grasp reflecting accurate perception of both metric shape and metric size. Large perspective changes occur when one locomotes into a workspace in which reaches-to-grasp are subsequently performed. Does the resulting perception of metric shape persist after the large perspective changes have ceased? Experiments 2 and 3 tested reaches-to-grasp with delays (Exp. 2, 5-s delay; Exp. 3, approximately 16-s delay) and multiple objects to be grasped after a single viewing. Perception of metric shape and metric size persisted yielding accurate reaches-to-grasp. We advocate the study of nested actions using a dynamic approach to perception/action.

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[PubMed - indexed for MEDLINE]

Bingham, Schmidt, and Rosenblum (Bingham, G. P., Schmidt, R. C., & Rosenblum, L. D. (1989). Hefting for a maximum distance throw: A smart perceptual mechanism. Journal of Experimental Psychology: Human Perception and Performance, 15, 507-528) found that skilled throwers could heft objects and select the weight in each size that they could throw to a maximum distance. Bingham et al. hypothesized that this affordance affects hefting and throwing in the same way so that hefting provides a window on throwing. Zhu and Bingham (Zhu, Q., & Bingham, G. P. (submitted for publication). Learning to perceive the affordance for long distance throwing: Smart mechanism or function learning? Journal of Experimental Psychology: Human Perception and Performance) found that unskilled throwers could not perceive this affordance, but they acquired the ability to perceive it as they acquired skill at throwing. The affordance property consists of a relation between object size and weight. We now investigated whether object size and weight come to affect throwing as it is learned and if so, how? Three groups of unskilled adults practiced throwing for a month, each with a different set of objects: constant size, constant weight, or constant density. Release angle and speed became more consistent as distances of throws improved, but only speeds exhibited mean changes. Object weight affected mean release speeds, following a power law, as found by Cross (Cross, R. (2004). Physics of overarm throwing. American Journal of Physics, 72, 305-312). Speeds decreased as weight increased. These findings showed that the affordance was not reflected directly in throwing performance and the hypothesis of Bingham et al. (1989) about how the affordance is perceived was not supported. An alternative account is now proposed.

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Previous research has shown that adults perceive affordances like the passability of apertures, climbability or crossability of steps and graspability of objects. In this study, the affordance for stepping over or onto barriers was examined in young children. This was done by placing three distinct barriers (a foam obstacle, a gap, and a single step up), which were scaled to body size, in the walking paths of 4- and 6-year olds and adults, and observing how they crossed the barriers. Age-related differences in the scaling of these actions corresponded to levels of movement variability, indicating that children as young as 4 years old are sensitive to their own constraints and scale their actions accordingly. These results indicate that affordances are not directly related to
leg geometry, but rather entail the dynamics of the developing perception-action system.


Both judgment studies and studies of feedforward reaching have shown that the visual perception of object distance, size, and shape are inaccurate. However, feedback has been shown to calibrate feedfoward reaches-to-grasp to make them accurate with respect to object distance and size. We now investigate whether shape perception (in particular, the aspect ratio of object depth to width) can be calibrated in the context of reaches-to-grasp. We used cylindrical objects with elliptical cross-sections of varying eccentricity. Our participants reached to grasp the width or the depth of these objects with the index finger and thumb. The maximum grasp aperture and the terminal grasp aperture were used to evaluate perception. Both occur before the hand has contacted an object. In Experiments 1 and 2, we investigated whether perceived shape is recalibrated by distorted haptic feedback. Although somewhat equivocal, the results suggest that it is not. In Experiment 3, we tested the accuracy of feedforward grasping with respect to shape with haptic feedback to allow calibration. Grasping was inaccurate in ways comparable to findings in shape perception judgment studies. In Experiment 4, we hypothesized that online guidance is needed for accurate grasping. Participants reached to grasp either with or without vision of the hand. The result was that the former was accurate, whereas the latter was not. We conclude that shape perception is not calibrated by feedback from reaches-to-grasp and that online visual guidance is required for accurate grasping because shape perception is poor.


G. P. Bingham, R. C. Schmidt, and L. D. Rosenblum (1989) found that, by hefting objects of different sizes and weights, people could choose the optimal weight in each size for throwing to a maximum distance. In Experiment 1, the authors replicated this result. G. P. Bingham et al. hypothesized that hefting is a smart mechanism that allows objects to be perceived in the context of throwing dynamics. This hypothesis entails 2 assumptions. First, hefting by hand is required for information about throwing by hand. The authors tested and confirmed this in Experiments 2 and 3. Second, optimal objects are determined by the dynamics of throwing. In Experiment 4, the authors tested this by measuring throwing release angles and using them with mean thrown distances from
Experiment 1 and object sizes and weights to simulate projectile motion and recover release velocities. The results showed that only weight, not size, affects throwing. This failed to provide evidence supporting the particular smart mechanism hypothesis of G. P. Bingham et al. Because the affordance relation is determined in part by the dynamics of projectile motion, the results imply that the affordance is learned from knowledge of results of throwing.


Feedback is a central feature of neural systems and of crucial importance to human behavior as shown in goal directed actions such as reaching-to-grasp. One important source of feedback in reach-to-grasp behavior arises from the haptic information obtained after grasping an object. We manipulated the felt distance and/or size of a visually constant object to explore the role of haptic information in the calibration of reaching and grasping. Crucially, our design explored post-adaptation effects rather than the previously documented role of haptic information in movement organization. A post-adaptation reach-to-grasp task showed: (1) distorted haptic feedback caused recalibration; (2) reach distance and grasp size could be calibrated separately but, if calibrated simultaneously, then (3) recalibration was greater when distance and size changed in a consistent (e.g. reaching for a larger object at a greater distance) rather than an inconsistent (e.g. a smaller object at a greater distance) fashion. These interactions reveal the integral nature of reach-to-grasp organization, that is, that reaching and grasping are integrated components of a single action system.


Phosphorescent square tiles (arranged to yield a single image size) were viewed in the dark by 56 monocular observers who utilized a chinrest. The targets were placed at one of three horizontal distances and at one of three eye heights, allowing us to study the relative effect of height in the visual field (HVF) and sagittal distance on observers’ verbal reports of the horizontal distance at which the object lay (near, middle, or far). In Experiment 1, we found that reports covaried primarily with HVF and, as predicted, they exhibited a weak paradoxical inverse relation with horizontal distance. In a second and third experiment, a visible surface was placed under the targets at the three eye heights in both dark and fully lighted conditions. In this situation, the inverse distance relation disappeared, and HVF no longer influenced the judgments of most observers. The
results show that information projected from relevant support surfaces is essential for veridical information about object distance. These results raise fundamental issues for perceptual researchers regarding how to decide when a cue has been properly delineated, given the assumption that the relation between a cue and what it specifies is probabilistic.

We investigated the ability to perceive the metric shape of elliptical cylinders. A large number of previous studies have shown that small perspective variations (< or =10 degrees) afforded by stereovision and by head movements fail to allow accurate perception of metric shape. If space perception is affine (Koenderink & van Doom, 1991), observers are unable to compare or relate lengths in depth to frontoparallel lengths (i.e., widths). Frontoparallel lengths can be perceived correctly, whereas lengths in depth generally are not. We measured reaches to evaluate shape perception and investigated whether larger perspective variations would allow accurate perception of shape. In Experiment 1, we replicated previous results showing poor perception with small perspective variations. In Experiment 2, we found that a 90 degrees continuous change in perspective, which swapped depth and width, allowed accurate perception of the depth/width aspect ratio. In Experiment 3, we found that discrete views differing by 90 degrees were insufficient to allow accurate perception of metric shape and that perception of a continuous perspective change was required. In Experiment 4, we investigated continuous perspective changes of 30 degrees, 45 degrees, 60 degrees, and 90 degrees and discovered that a 45 degrees change or greater allowed accurate perception of the aspect ratio and that less than this did not. In conclusion, we found that perception of metric shape is possible with continuous perspective transformations somewhat larger than those investigated in the substantial number of previous studies.

17. Wilson AD, Bingham GP. Identifying the information for the visual perception of relative phase. Percept Psychophys. 2008 Apr;70(3):465-76. School of Psychology, College of Life Sciences and Medicine, University of Aberdeen, Aberdeen, Scotland. andrew.wilson@abdn.ac.uk PMID: 18459257 [PubMed - indexed for MEDLINE]
The production and perception of coordinated rhythmic movement are very specifically structured. For production and perception, 0 degree mean relative phase is stable, 180 degrees is less stable, and no other state is stable without training. It has been hypothesized that perceptual stability characteristics underpin the movement stability characteristics, which has led to the development of a phase-driven oscillator model.
In the present study, a novel perturbation method was used to explore the identity of the perceptual information being used in rhythmic movement tasks. In the three conditions, relative position, relative speed, and frequency variables (motivated by the model) were selectively perturbed. Ten participants performed a judgment task to identify 0 degree or 180 degrees under these perturbation conditions, and 8 participants who had been trained to visually discriminate 90 degrees performed the task with perturbed 90 degrees displays. Discrimination of 0 degree and 180 degrees was unperturbed in 7 out of the 10 participants, but discrimination of 90 degrees was completely disrupted by the position perturbation and was made noisy by the frequency perturbation. We concluded that (1) the information used by most observers to perceive relative phase at 0 degree and 180 degrees was relative direction and (2) becoming an expert perceiver of 90 degrees entails learning a new variable composed of position and speed.

18. Wickelgren EA, Bingham GP. Trajectory forms as information for visual event recognition: 3-D perspectives on path shape and speed profile. Percept Psychophys. 2008 Feb;70(2):266-78. Department of Psychology, California State University, Sacramento, California 95819-6007, USA. wickelgren@csus.edu PMID: 18372748 [PubMed - indexed for MEDLINE]

Trajectory forms in events consist of the path shape and the speed profile (Bingham, 1987, 1995). Wickelgren and Bingham (2004) showed that adults can use the speed profile as visual information to recognize events from different perspectives, despite perspective distortions and differences in optical components. We now investigate whether adults can use trajectory forms to recognize events when the forms are viewed from 3-D perspectives and the path shape and speed profile vary. In Experiment 1, we tested recognition of events that differ in path shape (with the speed profile held constant). In Experiment 2, we tested recognition of events in which speed profiles were mapped onto circular paths. In Experiment 3, as a strong test of sensitivity to trajectory forms, we tested simultaneous separate recognition of speed profile and path shape when both varied across events. In all three experiments, events were viewed from multiple 3-D perspectives. The results show that both the shape of the path and the speed profile provide information for visual event recognition. We found that adults exhibit constancy (or view invariance) in being able to use trajectory forms to identify the same events when viewed from different 3-D perspectives.


What determines coordination patterns when both hands reach to grasp separate objects at the same time? It is known that synchronous timing is preferred as the most
stable mode of bimanual coordination. Nonetheless, normal unimanual prehension
behaviour predicts asynchrony when the two hands reach towards unequal targets, with
synchrony restricted to targets equal in size and distance. Additionally, sufficiently
separated targets require sequential looking. Does synchrony occur in all cases
because it is preferred in bimanual coordination or does asynchrony occur because of
unimanual task constraints and the need for sequential looking? We investigated
coordinative timing when participants (n = 8) moved their right (preferred) hand to the
same object at a fixed distance but the left hand to objects of different width (3, 5, and 7
cm) and grip surface size (1, 2, and 3 cm) placed at different distances (20, 30, and 40
cm) over 270 randomised trials. The hand movements consisted of two components: (1)
an initial component (IC) during which the hand reached towards the target while
forming an appropriate grip aperture, stopping at (but not touching) the object; (2) a
completion component (CC) during which the finger and thumb closed on the target.
The two limbs started the IC together but did not interact until the deceleration phase
when evidence of synchronization began to appear. Nonetheless, asynchronous timing
was present at the end of the IC and preserved through the CC even with equidistant
targets. Thus, there was synchrony but requirements for visual information ultimately
yielded asynchronous coordinative timing.

20. Mon-Williams M, Bingham GP. Calibrating reach distance to visual targets.
J Exp Psychol Hum Percept Perform. 2007 Jun;33(3):645-56. School of
Psychology, University of Aberdeen, Aberdeen, Scotland, UK. PMID:
17563227 [PubMed - indexed for MEDLINE]
The authors investigated the calibration of reach distance by gradually distorting the
haptic feedback obtained when participants grasped visible target objects. The authors
found that the modified relationship between visually specified distance and reach
distance could be captured by a straight-line mapping function. Thus, the relation could
be described using 2 parameters: bias and slope. The authors investigated whether
calibration generalized across reach space with respect to changes in bias and slope. In
Experiment 1, the authors showed that both bias and slope recalibrate. In Experiment 2,
they tested the symmetries of reach space with respect to changes in bias. They
discovered that reach space is asymmetric, with the bias shifting inward more readily
than outward. The authors measured how rapidly the system calibrated and the stability
of calibration once feedback was removed. In Experiment 3, they showed that bias and
slope can be calibrated independently of one another. In Experiment 4, the
authors showed that these calibration effects are not cognitively penetrable.

21. Wilson AD, Collins DR, Bingham GP. Human movement coordination
implicates relative direction as the information for relative phase. Exp Brain
Res. 2005 Sep;165(3):351-61. Epub 2005 May 14. Department of
Psychology, Indiana University, 1101 E10th St Bloomington, IN 47405-7007,
USA. PMID: 15895217 [PubMed - indexed for MEDLINE]
The current studies explore the informational basis of the coupling in human rhythmic movement coordination tasks. Movement stability in these tasks is an asymmetric U-shaped function of mean relative phase; 0 degrees is maximally stable, 90 degrees is maximally unstable and 180 degrees is intermediate. Bingham (2001, 2004a, 2004b) hypothesized that the information used to perform coordinated rhythmic movement is the relative direction of movement, the resolution of which is determined by relative speed. We used an experimental paradigm that entails using a circular movement to produce a linear motion of a dot on a screen, which must then be coordinated with a linearly moving computer controlled dot. This adds a component to the movement that is orthogonal to the display. Relative direction is not uniquely defined between orthogonal components of motion, but relative speed is; it was therefore predicted that the addition of the component would only introduce a symmetric noise component and not otherwise contribute to the U-shape structure of movement stability. Results for experiment 1 supported the hypothesis; movement that involved the additional component was overall less stable than movement that involved only the parallel component along which relative direction can be defined. Two additional studies ruled out alternative explanations for the pattern of data in experiment 1. Overall, the results strongly implicate relative direction as the information underlying performance in rhythmic movement coordination tasks.


Rhythmic movement coordination exhibits characteristic patterns of stability, specifically that movements at 0 degrees mean relative phase are maximally stable, 180 degrees is stable but less so than 0 degrees, and other coordinations are unstable without training. Recent research has demonstrated a role for perception in creating this pattern; perceptual variability judgments covary with movement variability results. This suggests that the movement results could be due in part to differential perceptual resolution of the target movement coordinations. The current study used a paradigm that enabled simultaneous access to both perception (between-trial) and movement (within-trial) stability measures. A visually specified 0 degrees target mean relative phase enabled participants to produce stable movements when the movements were at a non-0 degrees relationship to the target being tracked. Strong relationships were found between within-trial stability (the traditional movement measure) and between-trial stability (the traditional perceptual judgment measure), suggestive of a role for perception in producing coordination stability phenomena. The stabilization was incomplete, however, indicating that visual perception was not the sole determinant of
movement stability. Rhythmic movement coordination is intrinsically a perception/action system.


Previous studies have shown that people can use the information in trajectory forms to recognize visual events. A trajectory form is composed of the path of motion and the change in speed along that path. In past studies, however, only sensitivity to trajectory forms viewed from a single perspective was examined. The optical components change when an event is viewed from different perspectives, and the projected form of the trajectory is transformed. Does event recognition exhibit constancy despite these changes? In Experiment 1, participants were familiarized with five different trajectory forms viewed from a single perspective. Then the participants had to identify the same events viewed from different perspectives: from the side, at an angle, and entirely in depth. The participants exhibited perceptual constancy. Experiment 2 revealed, however, that both the change in optical components and the perspective transformations affected recognition.


We investigated whether distortions of perceived distance and shape could be captured by a single continuous one-to-one transformation of the underlying space. In Experiment 1, the participants reached to touch points around the perimeter of spherical targets viewed at five different distances, to yield simultaneous measures of perceived distance and shape. Different participants reached while using dynamic monocular, static binocular, or dynamic binocular vision. Thin plate spline (TPS) analysis was applied so as to transform a Cartesian grid in such a way as to carry the original target points to the mean reach locations. In all cases, discontinuities appeared in the transformed grid from folding of the space. In Experiment 2, the participants reached to points that lay at the same locus in reach space, but on different portions of the visible target spheres (e.g., front vs. side). The participants reached to different locations when the points were different with respect to shape (e.g., front vs. side) but reached to the same locations when the points were the same with respect to shape (left vs. right side). TPS analysis revealed discontinuities from holes torn in the underlying space. The results show that perceived distance and perceived shape entail different distortions and cannot be captured by a single continuous transformation of reach space.

Previous work has established that judgments of relative phase variability of 2 visually presented oscillators covary with mean relative phase. Ninety degrees is judged to be more variable than 0 degrees or 180 degrees, independently of the actual level of phase variability. Judged levels of variability also increase at 180 degrees. This pattern of judgments matches the pattern of movement coordination results. Here, participants judged the phase variability of their own finger movements, which they generated by actively tracking a manipulandum moving at 0 degrees, 90 degrees, or 180 degrees, and with 1 of 4 levels of Phase Variability. Judgments covaried as an inverted U-shaped function of mean relative phase. With an increase in frequency, 180 degrees was judged more variable whereas 0 degrees was not. Higher frequency also reduced discrimination of the levels of Phase Variability. This matching of the proprioceptive and visual results, and of both to movement results, supports the hypothesized role of online perception in the coupling of limb movements. Differences in the 2 cases are discussed as due primarily to the different sensitivities of the systems to the information. ((c) 2003 APA, all rights reserved)


We investigated the perception of causation via the ability to detect conservation violations in simple events. We showed that observers were sensitive to energy conservation violations in free-fall events. Furthermore, observers were sensitive to gradually perturbed energy dynamics in such events. However, they were more sensitive to the effect of decreasing gravity than to that of increasing gravity. Displays with decreasing gravity were the only displays in which the energy profile was dominated by (apparent) potential energy, leading to an asymmetric trajectory.


The ability to use trajectory forms as visual information about events was tested. A trajectory form is defined as the variation in velocity along a path of motion. In Experiment 1, we tested the ability to detect trajectory form differences between simulations of a freely swinging pendulum and a hand-moved pendulum. The trajectory form of the freely swinging pendulum was symmetric around the mid-point, whereas the
hand moved was not. In Experiment 2, we isolated trajectory form information by
varying the amplitudes of events while holding their periods constant. Straight path
versions of the harmonic events from Experiment 1 were tested. In Experiment 3, we
tested sensitivity to symmetrical peakening or flattening of trajectory forms. Participants
detected small differences in all three experiments. In Experiment 4, we tested the
ability to identify specific events based only on differences in trajectory forms.
Participants were able to identify four different events. We investigated properties of
trajectory forms that might potentially be detected and used as information, and we
found that the curvature yielded good results.

28. Bingham GP, Bradley A, Bailey M, Vinner R. Accommodation, occlusion,
and disparity matching are used to guide reaching: a comparison of actual
Dec;27(6):1314-34. Department of Psychology, Indiana University,
Bloomington 47405, USA. gbingham@indiana.edu PMID: 11766927
[PubMed - indexed for MEDLINE]
The authors used a virtual environment to investigate visual control of reaching and
monocular and binocular perception of egocentric distance, size, and shape. With
binocular vision, the results suggested use of disparity matching. This was tested and
confirmed in the virtual environment by eliminating other information about contact of
hand and target. Elimination of occlusion of hand by target destabilized monocular but
not binocular performance. Because the virtual environment entails accommodation of
an image beyond reach, the authors predicted overestimation of egocentric distances in
the virtual relative to actual environment. This was confirmed. The authors used -2
diopter glasses to reduce the focal distance in the virtual environment. Overestimates
were reduced by half. The authors conclude that calibration of perception is required for
accurate feedforward reaching and that disparity matching is optimal visual information
for calibration.

29. Wickelgren EA, Bingham GP. Infant sensitivity to trajectory forms. J Exp
Psychol Hum Percept Perform. 2001 Aug;27(4):942-52. Department of
Psychology, Indiana University, USA. PMID: 11518155 [PubMed - indexed
for MEDLINE]
The authors investigated whether infants are sensitive to visual event trajectory forms,
and whether they are sensitive to the underlying dynamics of trajectory forms. The
authors habituated 8-month-old infants to a videotaped event run either forward or
reversed in time and then switched them to the same event run in the opposite
direction. Infants dishabituated when switched to the event with the novel direction in
time, indicating sensitivity to the form of the trajectory. Infants exhibited equivalent
habitation rates and looking times for forward and reversed events, thus failing to
provide evidence that infants are sensitive to the underlying dynamics. In a partial
replication of this first experiment, the same pattern of results was found. Both
experiments revealed infant sensitivity to the trajectory forms, but not the underlying dynamics of events. The authors discuss implications for methods used in infant event perception studies.


Jacobs and Michaels (2001) have argued that increased precision in judgments of the viewing distance to a perceived event should be attributed in part to perceptual learning. They found that observers used feedback to attune to the appropriate information variables gradually. McConnell, Muchisky, and Bingham (1998) had found that observers used feedback to calibrate event-specific scaling coefficients, that the calibration of one type of event generalized to other types and that calibration occurred suddenly. We argue that Jacobs and Michaels must be partially correct and that, in our experiments, both calibration and perceptual attunement were required for accurate and precise judgments.


Relative phase has been studied extensively as a measure of interlimb coordination. Only two relative phases, namely 0 degrees and 180 degrees, are stably produced at the preferred frequency (approximately 1 Hz). When frequency is increased, movement at 180 degrees becomes unstable and relative phase typically switches to 0 degrees, which remains stable at higher frequencies. The current study was designed to investigate the perception of relative phase and of phase variability. Observers viewed two circles moving rhythmically in a computer display. Mean phases varied from 0 degrees to 180 degrees in 30 degrees steps. Phase variability at each mean phase varied from 0 degrees to 5 degrees, 10 degrees, and 15 degrees phase standard deviation (SD). Frequency of oscillation was either 0.75 Hz or 1.25 Hz. One group of ten observers judged mean relative phase. Another group judged phase variability. As predicted, increase in frequency yielded an increase in perceived phase variability at 180 degrees mean phase and other mean phases, but not at 0 degrees mean phase. In contrast, increase in actual phase variability affected judgments of 0 degrees mean phase most strongly. A second control experiment showed that the frequency effects were not produced by changes in display durations or frames per cycle of oscillation. The results are consistent with those in studies of interlimb coordination and indicate that understanding of interlimb coordination requires further investigation of phase perception.

We investigated whether forward or side-to-side head movements yielded more accurate and precise monocular egocentric distance information, as shown by performance in a reaching task. Observers wore a head-mounted camera and display to isolate the optic flow generated by their head movements and had to reach to align a stylus directly under a target surface. Performance in the two head movement conditions was also tested with normal monocular vision. We tested performance in the two head movement conditions when the observers were given haptic feedback and compared performance when haptic feedback was removed. Performance was both more accurate and more precise in the forward head movement condition than in the side-to-side head movement condition. Performance in the side-to-side condition also deteriorated more after the removal of haptic feedback than did performance in the forward head movement condition. In the normal monocular condition, performance was comparable for the two head movement conditions. The implications for enucleated patients are discussed.


Psychophysical studies reveal distortions in perception of distance and shape. Are reaches calibrated to eliminate distortions? Participants reached to the front, side, or back of a target sphere. In Experiment 1, feedforward reaches yielded distortion and outward drift. In Experiment 2, haptic feedback corrected distortions and instability. In Experiment 3, feedforward reaches with only haptic experience of targets replicated the shape distortions but drifted inward. This showed that outward drift in Experiment 1 was visually driven. In Experiment 4, visually guided reaches were accurate when participants used binocular vision but when they used monocular vision, reaches were distorted. Haptic feedback corrected inaccuracy and instability of distance but did not correct monocular shape distortions. Dynamic binocular vision is representative and accurate and merits further study.


Perception of relative phase and phase variability may play a fundamental role in interlimb coordination. This study was designed to investigate the perception of relative
phase and of phase variability and the stability of perception in each case. Observers
judged the relative phasing of two circles rhythmically moving on a computer display.
The circles moved from side to side, simulating movement in the frontoparallel plane, or
increased and decreased in size, simulating movement in depth. Under each viewing
condition, participants observed the same displays but were to judge either mean
relative phase or phase variability. Phase variability interfered with the mean-relative-
phase judgments, in particular when the mean relative phase was 0 degrees.
Judgments of phase variability varied as a function of mean relative phase.
Furthermore, the stability of the judgments followed an asymmetric inverted U-shaped
relation with mean relative phase, as predicted by the Haken-Kelso-Bunz model.

35. Bingham GP, Schmidt RC, Zaal FT. Visual perception of the relative
phasing of human limb movements. Percept Psychophys. 1999
Feb;61(2):246-58. Department of Psychology, Indiana University,
Bloomington 47405, USA. gbingham@indiana.edu  PMID: 10089759
[PubMed - indexed for MEDLINE]
Studies of bimanual coordination have found that only two stable relative phases (0
dergree and 180 degrees) are produced when a participant rhythmically moves two
joints in different limbs at the same frequency. Increasing the frequency of oscillation
causes an increase in relative phase variability in both of these phase modes. However,
relative phasing at 180 degrees is more variable than relative phasing at 0 degree, and
when the frequency of oscillation reaches a critical frequency, a transition to 0 degree
occurs. These results have been replicated when 2 people have coordinated their
respective limb movements using vision. This inspired us to investigate the visual
perception of relative phase. In Experiment 1, recordings of human interlimb
oscillations exhibiting different frequencies, mean relative phases, and different
amounts of phase variability were used to generate computer displays of spheres
oscillating either side to side in a frontoparallel plane or in depth. Participants judged the
stability of relative phase. Judgments covaried with phase variability only when the
mean phase was 0 degree or 180 degrees. Otherwise, judgments covaried with mean
relative phase, even after extensive instruction and demonstration. In Experiment 2,
mean relative phase and phase variability were manipulated independently via
simulations, and participants were trained to perceive phase variability in testing
sessions in which mean phase was held constant. The results of Experiment 1 were
replicated. The HKB model was fitted to mean judgment standard deviations.

36. McConnell DS, Muchisky MM, Bingham GP. The use of time and trajectory
forms as visual information about spatial scale in events. Percept
Psychophys. 1998 Oct;60(7):1175-87. Department of Psychology, Indiana
University, Bloomington, IN 47405, USA. dsmcconn@indiana.edu  PMID: 9821779  [PubMed - indexed for MEDLINE]
Spatial metrics are lost but temporal metrics are preserved in the mapping from events
to optic flow. In inanimate events governed by gravity, temporal scale is linked to spatial
scale in ways specific to particular events. We tested whether time can be used as
information about spatial scale in visually recognizable events. On average, observers were able to judge object size in event displays that eliminated information other than time and trajectory forms. However, judgment variability was substantial. After feedback on one event, observers judging distance performed better and generalized training to other events. Observers are sensitive to the general form of the scaling relation, but they require feedback to attune event-specific constants.


cpagano@clemson.edu PMID: 9706709 [PubMed - indexed for MEDLINE]

Monocular perception of egocentric distance via optic flow generated by head movement toward a target was investigated with a helmet-mounted video camera and display. Ability to perceive target distance was assessed with 2 response measures: verbal reports and reaches. Systematic and random errors differed as a function of the response measure. Verbal estimates of targets within and beyond reach were obtained before and after the performance of reaches to targets within reach. Systematic errors of verbal estimates changed but did not decrease overall. Random error decreased. Verbal estimates and reaches were performed concurrently to targets within reach. Verbal and reaching errors were uncorrelated. Verbal judgments appear to have been anchored using the range of distances experienced while reaching rather than being calibrated to the perceptual information itself. Discussion focuses on the advantages of action response measures.

gbingham@indiana.edu PMID: 9483825 [PubMed - indexed for MEDLINE]

In this investigation of monocular perception of egocentric distance, the authors advocate the necessity of a perception-action approach because calibration is intrinsic to definite distance perception. A helmet-mounted camera and display were used to isolate optic flow generated by participants' head movements toward a target, and participants' reaches to place a stylus either in a target hole (Experiments 1, 2, and 4) or aligned under a target surface (Experiment 3) were analyzed. Conclusions are that binocular distance perception is accurate, monocular distance perception yields compression that is not eliminated by feedback, but feedback is used to eliminate underestimation generated by restriction of the size of the visual field.

The authors investigated event dynamics as a determinant of the perceptual significance of forms of motion. Patch-light displays were recorded for 9 simple events selected to represent rigid-body dynamics, biodynamics, hydrodynamics, and aerodynamics. Observers described events in a free-response task or by circling properties on a list. Cluster analyses performed on descriptor frequencies reflected the dynamics. Observers discriminated hydro- versus aerodynamic events and animate versus inanimate events. The latter result was confirmed by using a forced-choice task. Dynamical models of the events led us to consider energy flows as a determinant of kinematic properties that allowed animacy to be distinguished. Orientation was manipulated in 3 viewing conditions. Descriptions varied with absolute display orientation rather than the relative orientation of display and observer.


Bingham and Muchisky (1993) found that observers were very accurate in determining the location of the center of mass in planar objects. Systematic errors were affected primarily by object orientation, while random errors varied with the amount of symmetry. Radial and axial reflective symmetry affected errors in different ways. In the current study, we investigated the different effects of axial reflective versus rotational symmetry. All random errors decreased with increasing rotational symmetry. Axial reflective symmetry further reduced errors in the direction perpendicular to the axis. We replicated the effect on systematic error of orientation. However, we also found an effect of the perturbation of symmetry that suggested that observers used an approximation to symmetry. To investigate this possibility, we constructed a series of objects in which axial reflective symmetry was established and then perturbed by varying amounts. We found that systematic errors were structured by the underlying approximate symmetries, and we discuss the problem of quantifying symmetry.


Center of mass perception was investigated by varying the shape, size, and orientation of planar objects. Shape was manipulated to investigate symmetries as information. The number of reflective symmetry axes, the amount of rotational symmetry, and the presence of radial symmetry were varied. Orientation affected systematic errors. Judgments tended to undershoot the center of mass. Random errors increased with...
size and decreased with symmetry. Size had no effect on random errors for maximally symmetric objects, although orientation did. The spatial distributions of judgments were elliptical. Distribution axes were found to align with the principle moments of inertia. Major axes tended to align with gravity in maximally symmetric objects. A functional and physical account was given in terms of the repercussions of error. Overall, judgments were very accurate.


Physical constraints produce variations in the shapes of biological objects that correspond to their sizes. Bingham (in press-b) showed that two properties of tree form could be used to evaluate the height of trees. Observers judged simulated tree silhouettes of constant image size appearing on a ground texture gradient with a horizon. According to the horizon ratio hypothesis, the horizon can be used to judge object size because it intersects the image of an object at eye height. The present study was an investigation of whether the locus of the horizon might account for Bingham's previous results. Tree images were projected to a simulated eye height that was twice that used previously. Judgments were not halved, as predicted by the horizon ratio hypothesis. Next, the original results were replicated in viewing conditions that encouraged the use of the horizon ratio by including correct eye height, gaze level, and visual angles. The heights of cylinders were inaccurately judged when they appeared with horizon but without trees. Judgments were much more accurate when the cylinders also appeared in the context of trees.


The point of observation translates with eye movement because it is not coincident with the center of rotation in the eye. "Ocular occlusion" results. The amount of optical structure revealed by eye rotation depends on the distances of the occluding and occluded surfaces. The method of adjustment was used in Expt 1 to investigate the amount of structure detected at distances up to 1 m. In Expt 2, a forced-choice method was used to confirm predictions based on the assumption that the point of observation is in the entrance pupil at 11 mm from the center of rotation. (The location of the point of observation in the eye had not been measured previously.) Experiment 3 investigated the use of ocular occlusion to detect separation of surfaces in depth.

Task dynamics corresponding to rhythmic movements emerge from interactions among dynamical resources composed of the musculature, the link segments, and the nervous and circulatory systems. This article investigated whether perturbations of interlimb coordination might be effect over circulatory and nervous elements. Stiffness of wrist-pendulums oscillated at a common tempo and at 180 degrees relative phase was perturbed through the use of tonic activity about an ankle. Left and right stiffnesses, the common period, and the phase relation all changed. Stiffnesses increased with ankle torque in proportion to the wrist's inertial load. Despite different changes in stiffness at the two wrists, isochrony was preserved. The stability was shown to be consistent with the proportionality of changes in stiffness to the inertial loads. The phase departed from antiphase in proportion to the asymmetry of inertial loads. The size of departures decreased with increasing ankle torque. An account was developed in terms of muscular, circulatory, and nervous functions.


Objects for throwing to a maximum distance were selected by hefting objects varying in size and weight. Preferred weights increased with size reproducing size-weight illusion scaling between weight and volume. In maximum distance throws, preferred objects were thrown the farthest. Throwing was related to hefting as a smart perceptual mechanism. Two strategies for conveying high kinetic energy to projectiles were investigated by studying the kinematics of hefting light, preferred, and heavy objects. Changes in tendon lengths occurring when objects of varying size were grasped corresponded to changes in stiffness at the wrist. Hefting with preferred objects produced an invariant phase between the wrist and elbow. This result corresponded to an optimal relation at peak kinetic energy for the hefting. A paradigm for the study of perceptual properties was compared to size-weight illusion methodology.


Observers are able to judge accurately the weight lifted by another person when only the motions of reflective patches attached to the lifter's major limb joints and head can be seen (Runeson & Frykholm, 1981). What properties of these complex kinematic patterns allow judgments of weight to be made? The pattern of variation in velocity of the lifted object over position is explored as a source of information for weight: It is found to provide limited information. How are variations in kinematic patterns scaled to allow judgments of weight, a kinetic quantity? The possibility of a source of information for scaling in the kinematics is investigated. Judgments based only on patch-light
displays are accurate to a degree that is improved by an extrinsic scaling basis. Finally, the sensitivity to scaling of alternative metrics used in judging is explored. Intrinsic metrics are discovered to be less sensitive to the absence of an extrinsic basis for scaling.