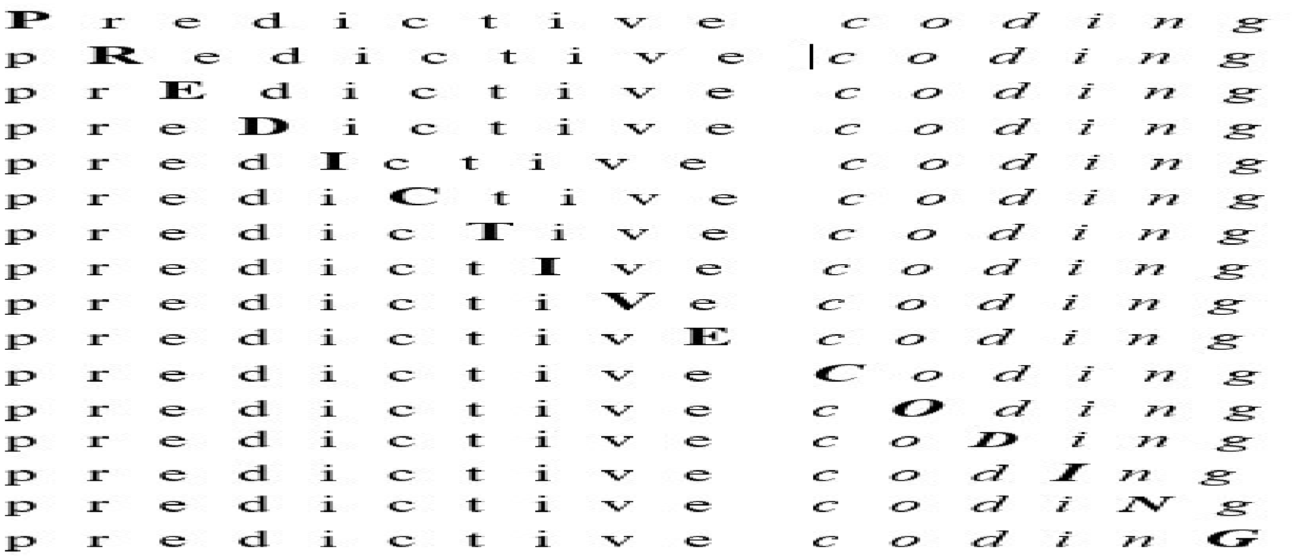
How Predictive Coding Is Afforded and How the Cortical Streams Process Prediction Errors During Online Execution

The Complete Clarification of Predictive Coding Across All Motor Actions



Caught In A Line
The explanatory model of all motoric movement actions

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The Playing of the Game Pong

Abstract

Predictive coding and predictive processing occupy a central place in cognitive neuroscience, yet their role in motor control remains fundamentally unresolved. Despite decades of theorizing, no consensus has emerged within the scientific community about how prediction and prediction errors are concretely instantiated during action execution. The debate has remained largely abstract, with frameworks such as the Free Energy Principle offering metaphorical formulations but no mechanistic clarity.

This article provides, for the first time, a concrete and testable account of how predictive coding arises in motoric actions. Using the computer game *Pong* as a paradigmatic case, it demonstrates that the predictive dynamics of the pong ball and the paddle cannot be collapsed into a single perceptual–motor stream. Instead, they compel recognition of two autonomous phenomena, each with its own trajectory, latent and manifest positions, and prediction errors. Crucially, these independent predictive processes converge only at an intersection point, where perception and action are projectively coupled in real time.

In this way, the study reveals how affordances, feedback, and online correction are structurally organized in motor control, thereby moving beyond abstract metaphor toward genuine mechanistic explanation. The findings thus represent a decisive step in clarifying the predictive foundations of perception–action coupling.

Keywords: *predictive coding, predictive processing, prediction errors, Pong, affordances, action trajectory shapes, projective perception, online motor control, intersection point.*

Introduction

The cognitive and neurosciences remain in what Thomas Kuhn (1962) described as a *pre-paradigmatic stage*—a developmental period in which no consensus exists on the fundamental principles that should guide research. Nowhere is this more evident than in the domain of perception and motor action. Despite major advances in describing neural correlates and behavioral dynamics, there is still no theoretical framework that convincingly explains how prediction and prediction errors are structurally instantiated in the execution of action.

Predictive coding and predictive processing have become central paradigms in this debate. They emphasize the role of anticipatory models and the corrective influence of prediction errors, and these ideas resonate with established neuroscientific evidence of feedback mechanisms. Yet the explanatory elaborations of these frameworks remain abstract, frequently couched in metaphorical terms such as “surprise reduction” or “free energy minimization.” While they provide a compelling language for unification, they do not offer a mechanistic account of how perception–action coupling is realized in concrete, testable contexts. As a result, decades of theorizing have not yielded consensus on how predictive principles are enacted within real-time motor control.

This article provides, for the first time, a direct resolution of this problem. By examining the computer game *Pong*, it demonstrates that predictive coding in motor control cannot be reduced to a single perceptual–motor stream. Instead, the dynamics of the pong ball and the paddle compel recognition of two autonomous phenomena, each unfolding along its own trajectory with latent and manifest positions and their respective prediction errors. Crucially, these autonomous predictive processes converge only at an intersection point, where perception and action are projectively coupled.

Through this analysis, *Pong* emerges not as a trivial game, but as a paradigmatic demonstration of how predictive coding and predictive processing are instantiated in practice. It reveals the implicit projective and anticipatory nature of motor action, showing that affordances, feedback, and online correction are structurally organized through the dual autonomy of the environmental (ball) and egocentric (paddle) movement. In contrast to abstract theoretical formulations, this model offers a concrete and testable explanatory framework—marking a decisive step toward resolving the long-standing lack of consensus in the field.

The Movement of the Pong Ball

How the Perception of the Movement of the Pong Ball is Afforded

The Perception of the Manifest Positions of the Pong Ball Forms a Line[1]

The perception of the movement of the pong ball encompasses the catch action that is universally present in any conceivable motor action. After only a few repeated observations of the pong ball's movement, one becomes capable of predicting the further course of the approaching ball trajectory. This is not because of conscious calculation or the availability of complete visual information, but because the visual system immediately generates a projective image that is implicitly action relevant.

At the very first appearance of the pong ball on the screen, there is initially no clear pattern. However, as soon as several successive manifest positions become visible, an implicit perceptual image of a line begins to form, along with a corresponding perceptual projection of the expected continuation of the movement through space and time. This projected image is not exact, but sufficiently *precise* to allow timely anticipation of the ball's *global* future course[2].

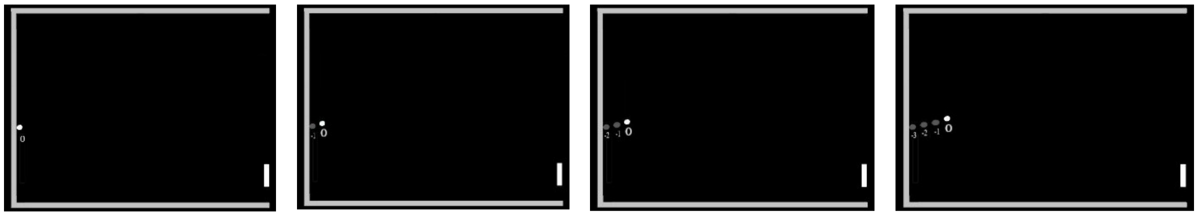
Crucial here is the assumption that all perceptible, actual positions of the pong ball will always emerge from one another c.q. each new position of the pong ball will have to sprout from its previous position. This simple factual principle enables the perceptual system to generate an early-stage coarse linear projection, which in turn allows for an equally early projection of the egocentric movement of the paddle.

Within the game of Pong, this is particularly effective. After only a few early manifest positions of the pong ball, two things can already be predicted: 1. *Where* the ball will exit the screen, and 2. *When* that event will occur. This latter temporal component is known as the *tau*-value and during the game this will encompass the time-to-contact between ball and paddle. Although much more important than the

[1] What follows is a step-by-step exposition of the projective affordance of the movement of the pong ball. At each stage, however, it is essential that the analysis is continuously referred back to the full (complex and dynamic) phenomenon of which the pong ball constitutes only a partial element.

[2] The explanatory model of the motoric movement action introduces the seemingly paradoxical term *precise global*. Predictions can never be exact in detail but can specify with precision the global zone c.q. the global fluctuation boundaries within which the action will unfold. The term reflects the paradigm shift that action execution and perceptual processes are, by nature, reductive rather than representational.

precision of this prediction is the fact that the prediction itself arises as an ecological prerequisite for initiating any egocentric motor action at all.



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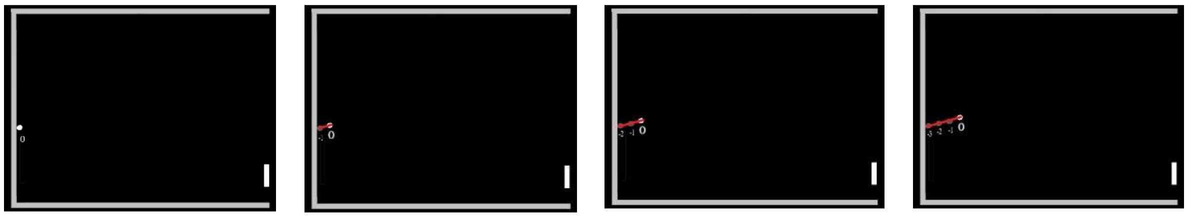
The observation of the initial manifest position (fig. 1) of the pong ball, in isolation, yields little immediate information. Nonetheless, it is crucial to assert that the subsequent trajectory of the ball must necessarily proceed c.q. sprout from this initial position[3]. This constitutes an incontrovertible empirical fact. The manifest positions of the pong ball must always emerge from one another, thereby forming a perceptual representation of a continuous line.



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The traversal of the subsequent early positions P(1–4) of the pong ball subsequently enables the formation of a perceptual image of the sequence of manifest locations. This image develops as a progressively unfolding linear form in both space and time. In which it can factually be established that the perception of the initial position P(0) of the pong ball always constitutes the front of the perceptual representation of the manifest trajectory.

Caught In A Line - The Pong Ball Must Continue Its Linear Movement

The empirical conclusion that the first visible manifest positions of the pong ball form a line may at first seem straightforward. However, it quickly reveals a deeper structural principle: each new position of the ball must necessarily emerge from the previous one. Which continuity can be automatically interpreted as an action trajectory shape.

As a result, we do not perceive the pong ball as a series of isolated points, but rather as a moving object embedded within one single overarching projective structure. The perception of motion thus presupposes a unifying framework in which spatial succession is integrated into one coherent temporal experience, rather than being perceived as a sequence of disconnected events.

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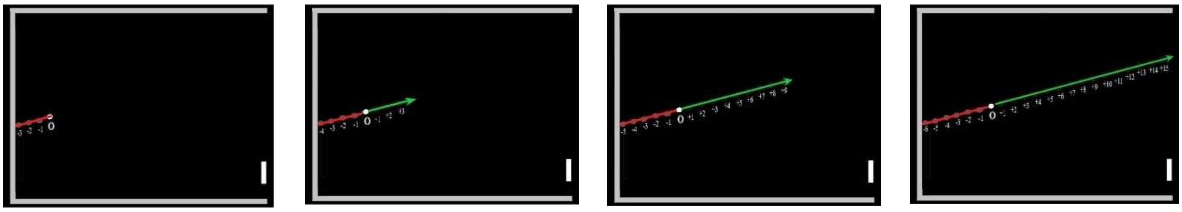
[3] The appearance of the initial singular position P(0) of the pong ball offers little information regarding the line segment shape of the future subsequent positions. However, this is the point where the perception regarding the movement of the pong ball is reduced most and this understanding constitutes a radical reconceptualization of the classical notion of perception as a process oriented toward truth or objective representation. Within this fundamentally revised framework, perception is understood not as a mirror of reality but as a reductive system: the brain does not aim to replicate the world as it is but instead organizes sensory input in such a way that the range of action-relevant possibilities is drastically reduced. The implicit projection of latent action trajectory shapes, such as the anticipated linear path of the pong ball, is thus not a step toward objective reconstruction, but rather a process of functional convergence. In this view, perception becomes a pragmatic mechanism for constraining complexity, not revealing truth.



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When the pong ball reaches position P(0), an immediate expectation arises concerning the likely location of the next position P(+1). Which expectation will be constrained by both the speed and direction encoded in the manifest trajectory. Due to the fact that this predictive process is reinitiated with each new position P(0) we are capable to construct a perceptual image of the still latent part of the ball's upcoming path. So this expectation does not result from conscious reasoning but rather from an implicit continuation of the trajectory, derived from the direction and velocity established in the manifest sequence. In this way the visual system spontaneously constructs a projection of the latent segment of the incoming pong ball trajectory shape. A part that is not yet visible but is nonetheless implicitly and predictively projected.
In the game of Pong, this projection process operates with particular efficiency due to the constant speed and linear trajectory of the pong ball. As a result, a consistent cognitive basis regarding the expected motion behavior of the pong ball can be constructed after only a few observations. The ball, as it were, "*promises*" a particular trajectory, and the perceptual system anticipates to that promise. Not with absolute certainty, but with sufficient probability to initiate egocentric action. Which in this case means that you are capable to move the paddle in time towards an intersection point with the pong ball.
So the egocentric throw action regarding the paddle is thus not oriented toward the ball itself, but toward its implicit projection. The current position P(0) of the pong ball solely encompasses the visible, manifest front of an incoming ball trajectory shape but has already been constructed completely within our perception processes. So acting does not respond to what *is*, but to what *is about to be*.

Predictive Coding as Implicit Projective Perception

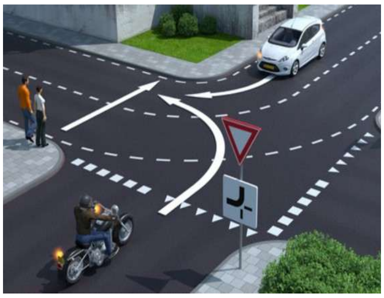
The preceding analysis demonstrates that the perception of motion is fundamentally projective in nature, as future movements must emerge from the manifest positions of the action object. This leads to the empirical conclusion that all future perceptions (of all future movements) must likewise emerge from prior manifest observations.
Therefore, any moving action object is not perceived by the visual system as a sequence of discrete moments but rather as an implicit trajectory. In which the most probable future positions are embedded as sound as possible. So, this projected trajectory is not the result of conscious computation, but an automatically generated structure based on minimal visual input. The explanatory model presented here demonstrates that this process is not optional or context-dependent, but structurally necessary and always operative. In fact, the model reveals that it is a foundational condition for motor behavior itself: without this implicit *afforded* projection, goal-directed movement would definitely not be possible.
Our perceptual organs are not passive receptors originally, but dynamic temporal comparators. From an evolutionary perspective, the visual system had to detect immediately (and automatically) whether something was approaching[4], in which direction, and at what speed (whether it concerned food, a threat, or a mating partner). This evolutionary imperative led to an embedded mechanism that

[4] Long before conscious cognitive evaluation could establish what, exactly, was approaching, the perceptual system was already responding through predictive mechanisms.

transforms perceived manifest motion into projected continuation: a latent trajectory. Thus, while the current position P(0) is always perceived as the visible front of the motion, within our perception processes it is also interpreted as the strict division between the manifest and latent part of the complete action trajectory shape.

Traditional models of predictive coding (as in Friston[a] and Clark[b]) propose that the brain generates hierarchical predictions continuously updated through error correction. The model presented here shifts that perspective fundamentally. In this view predictive coding is not treated as an optional strategy or cognitive tool but as an unavoidable, automatic mechanism embedded within the perceptual organs themselves. Every perception of motion implicitly generates a projective structure in which future positions are predicted and as cognitive familiarity with specific movement patterns increases, the success of this predictive process improves accordingly.

This implicit predictive structure manifests across a wide range of contexts. The following three examples illustrate how the perceptual system, through predictive coding, attempts to forecast future positions of action objects. The examples vary in success depending on the level of: 1. The cognitive familiarity, and 2. The regularity, regarding the motion behavior.


a b c

a. Evolutionary Anticipation to Threat - From an evolutionary perspective, our first perceptual impulse is to predict whether an approaching object poses a threat. When for example perceiving a lion, the animal's successive manifest positions are automatically compared and extended into a projective latent trajectory. Within this structure, future positions are required to emerge from the manifest ones. If an observer possesses sufficient cognitive knowledge[5] about the typical movement behavior of predators, they can reliably estimate whether the projected action trajectory shape is directed at their own body (direction), and with what velocity rate that trajectory converges toward zero (*tau*-value).

b. Projective Prediction in Traffic Perception - In traffic situations, the perceptual system applies the same projective structure. Based on an extensive basis of general cognitive traffic knowledge, the manifest positions of other road users are used to implicitly derive their expected, specific action trajectory shapes. Conversely the goal in here is to avoid intersection points between one's own egocentric action trajectory shape and those of others. Automatic implicit prediction of the latent parts is essential for one must quickly assess whether another's trajectory intersects with one's own action-trajectory and with what *tau*-value this intersection may indicate a potential collision.

c. The Unpredictable Balloon - When inflating a balloon, failing to tie it, and releasing it, a situation emerges in which reliable predictions are nearly impossible. Although the successive positions of the balloon still technically emerge from one another—meaning that the balloon remains, formally, within a linear structure—its chaotic movement prevents the formation of any stable representation of its

[5] U moet hier denken aan een veelheid van gestapelde kennis. Alle motorische handelingen worden in lijnen waargenomen waardoor er al heel veel universele ballistische kennis aanwezig is. Hetgeen via specifiekere bewegingskennis van dieren in het algemeen doorloopt tot hele specifieke kennis over deze ene leeuw.

motion behavior. There is no consistent relationship between manifest and latent positions, meaning the (precise) global fluctuation boundaries of the balloon's latent action trajectory shape fall outside the scope of what humans can perceptually predict. As a result, no reliable cognitive foundation can be formed for predicting either the shape of the action trajectory shape or its *tau*-value.

The Pong Ball's Actual Position will be Reduced to One Overarching Phenomenon Within the Perception of the Complete Incoming Pong Ball Trajectory Shape

When examining the perceptual process more closely it becomes clear that at any given moment only one actual position P(0) at time *t*(0) of the pong ball is visually perceived directly. The preceding positions P(–x) c.q. the previously manifest locations have already disappeared and the predicted future positions P(+x) c.q. the upcoming locations of the pong ball are not yet present. However, it is crucial to understand that the observation of the pong ball's position at P(0) compels nothing more than a perceptual fast fading snapshot within the entire continuum of actual motion representations constructed by the perceptual system.

This apparent paradox, perceiving only a single manifest moment while acting upon an entire action trajectory shape, is precisely where the explanatory model of the motoric movement action plays a central role. The current position P(0) cannot be understood in isolation; it only gains functional meaning within a projective visual representation in which both past and future positions of the action object are implicitly linked as part of a unified action trajectory shape. Solely this complete overarching phenomenon will supply the necessary requirements for successful task execution.

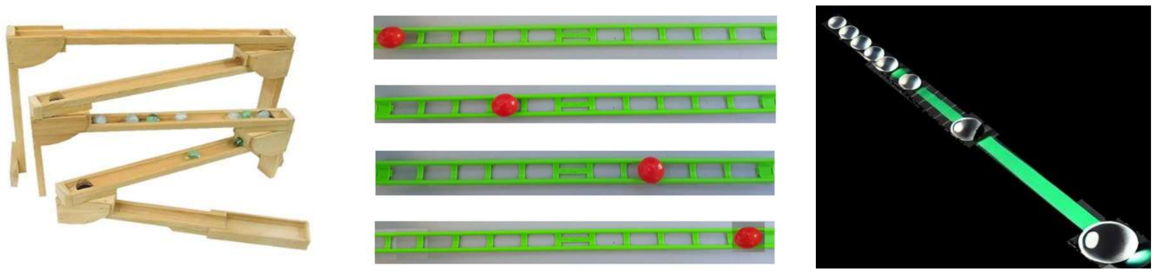
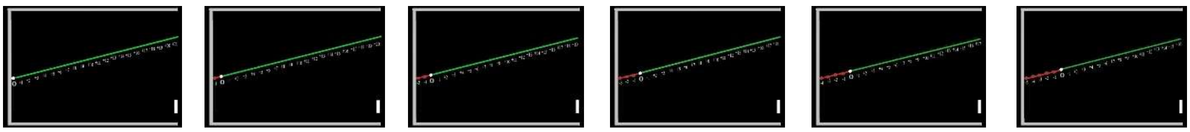


Fig.: *A perceptual image of the manifest or future latent positions P(+x) of the action object becomes rarely visible, except for motor tasks like writing or pouring liquids. Yet, the explanatory model demonstrates that this implicit projective structure must be necessarily present in every goal-directed action. Without an actual position (of the marble), there is no starting point for projection and without projection (of the marble run) the marble has no functional meaning. Only through their obligatory coupling does the functional basis emerges.*

A striking metaphor is that of a marble in a marble run. It immediately clarifies that a marble without a track and vice versa a track without a marble are both meaningless. Only in the coupling of object and trajectory does meaning emerge. The same applies to the pong ball. Its position P(0) gains perceptual significance only within the implicit complete linear structure of the incoming ball trajectory shape. This projection is implicitly constructed by the perceptual system as soon as a minimal sequence of manifest positions has been observed.



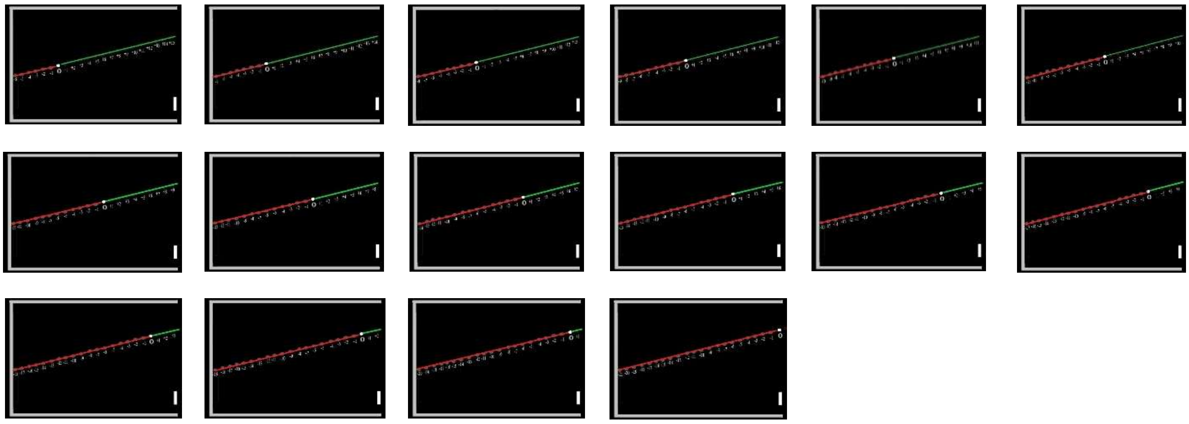


Fig.: *What applies to a classic wooden marble run also applies to the pong ball within the perceptual image of the incoming ball trajectory shape. The actual position P(0) is consistently located at the front of the perceptual image of the manifest trajectory and thus precisely marks the exact transition between which positions of the pong ball have already been visible (the manifest trajectory) and what is still implicitly predicted (the latent trajectory). Crucially, this latent segment always logically and visually will have to emerge c.q. to stem from the manifest part. It is not a disconnected extrapolation, but the natural continuation of an already-formed linear structure. As such, the current position P(0) always represents the exact boundary between all manifest and latent positions of the pong ball.*

This projective integration of manifest and latent positions ensures that the pong ball does not appear as an autonomous object but rather as the single visible point within an implicitly constructed action trajectory shape. Or in other words, the ball is not perceived as an isolated entity but represents the current location within a visual continuum that encompasses both direction and time. This line is not an optional addition to perception. It is perception. So, perception does not register what *is* but organizes what *can happen* based on what has already been established.

The *Tau*-Value of the Pong Ball Within the Incoming Ball Trajectory Shape

The explanatory model of the motoric movement action convincingly demonstrates that there are absolutely no separate elements within the perception–action coupling but conversely constitutes one single undivided phenomenon. This unity serves a critical function, as illustrated in the marble–marble run analogy. Because besides perceiving the shape of the final segment of the incoming ball trajectory shape, it is equally essential to perceive *when* the pong ball will reach the end of that line.

1

2

Fig.: *The small and large version of the cat-and-mouse game encompasses the clear presence of both a marble and a marble run. However, because the opaque track obscures most of the marble's successive positions P(0), the relational perception–action coupling phenomenon becomes difficult to perceive. As a result, observers are unable to form a reliable mental representation of the one-*

dimensional closing of the gap. Mere mortals will therefore often fail to catch either the marble (1) using a cup or the melon (2) using a bat within their egocentric throwing action.

Because at the end of the incoming pong ball trajectory, an intersection point must be realized with the egocentric action trajectory shape of the paddle. To achieve a successful outcome, it is essential that the paddle will be there when the *tau*-value of the incoming pong ball trajectory reaches zero. This time-to-contact (ttc) can only be determined by perceiving the rate at which the perceptual image of the latent segment of the incoming pong ball trajectory converges toward zero. Such perception can solely occur if the observer has implicitly constructed a perceptual image of the entire phenomenon as one unified structure.

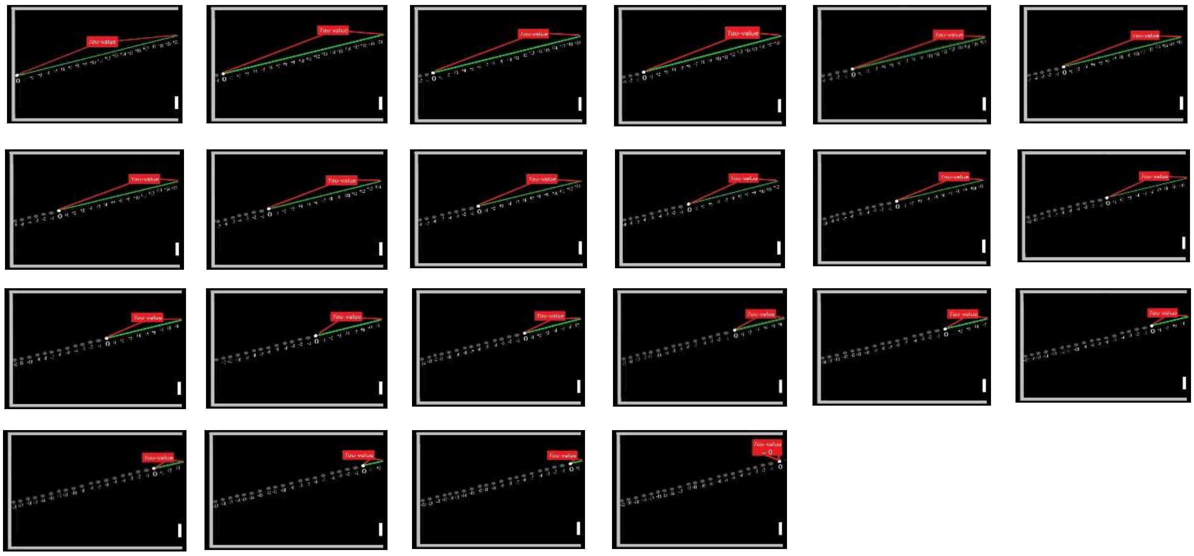
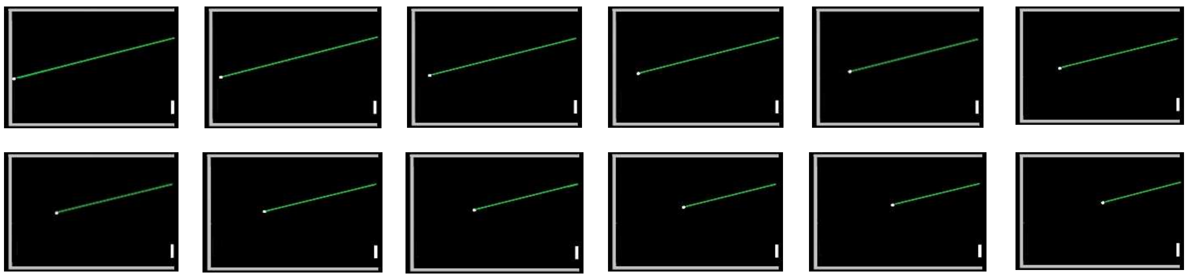


Fig.: *In Pong the tau-value c.q. the perceived distance to the expected point of intersection decreases at a constant rate. This enables the perceptual system to estimate the approaching moment of impact with 'precise global' precision.*

The Complex Perception of the *Tau*-Value Can Be Reduced to the Simplest One-Dimensional Observation – The Ecological Justification

The preceding explanation of projective line formation, *tau*-values, and manifest and latent action-trajectory structures might give the impression that perception is an ultra-demanding cognitive task and a highly intensive computational process. If such processes had to be executed with this level of computational complexity, the model would be well-nigh ecologically implausible. Our perceptual system would then constantly need to perform intricate calculations in order to initiate action.

On the contrary, the opposite is true. The strength of the explanatory model lies precisely in its reduction of this underlying complexity to a single, extremely simple and visually observable phenomenon: the straightforward disappearance of a line segment toward its endpoint.



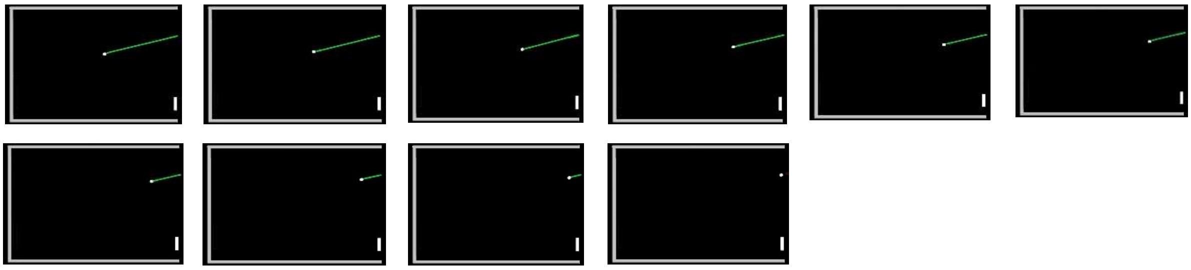


Fig.: *The perception of the complex process of the tau-value approaching zero can be reduced to a very simple one-dimensional observation: the disappearance of a line. Just as a boat approaching a dock gradually reduces the visible gap between the boat and the dock, the same occurs in the incoming pong ball trajectory shape. The space between the actual position of the pong ball and the projected goal of the action trajectory shape progressively disappears.*

This process requires no explicit calculation or representation. The *tau*-value (Lee, [c]), c.q. the remaining time-to-contact, manifests as the straightforward visual experience of a line segment that simply becomes progressively shorter. As with a boat slowly approaching a quay. One does not see a static distance, but rather a *disappearing* distance. A vanishing gap[6]. It is within this vanishing gap that the essence of time-to-contact is embedded, without it ever needing to be explicitly computed.

In the case of the pong ball, the latent gap between the ball and the intersection point with the paddle is visually expressed through the *disappearance* of the line segment shape between their respective projections. Just as the latent gap from the paddle to that same intersection point is perceived in an identical way.

The following section will explain how the movement of the paddle toward the intersection point with the incoming trajectory likewise approaches to zero in a similarly simple manner. Thus, a highly complex dynamic system, composed of two autonomous sets of perception–action couplings, is perceptually reduced to the very simple experience of two action trajectory shapes vanishing toward a common point of intersection.

[6] Or as D.N. Lee called this: “The gap is situated between the state where the action object is in now and the state where it wants to be in”.

The Movement of the Pong Ball

How The Cortical Streams Mediate the Online Control of the Pong Ball's Movement

Introduction

The previous section describes how the perception of the movement of the pong ball is afforded within Gibson's ecological framework. It clearly demonstrates that, based on the manifest positions of the pong ball, reliable perceptual predictions can be made about future positions the ball cannot escape. Due to the fact that the latent positions of any action object must always emerge from the manifest ones and that they are always constrained to the shape of the manifest trajectory and the speed regarding those manifest positions.

However, these early predictions represent *precise global* projective images. They are pertinently not formed to deliver an exact representation of the future action trajectory shape. As would never have been the goal within parsimonious ecologically evolving organisms. The purpose of this early prediction is solely to allow action to begin as quickly as possible and only encompasses a coarse projection of the fluctuation boundaries within which an action is most likely to unfold.

Ergo, these early estimates are merely predictions within our perception. Our subjective perception. Which may do its utmost to strive toward accuracy, but in fact never can. Even though the actual position of the action object may be perceived directly, it still remains a perception. So, the perceptual image of the future prediction of the latent part of the action trajectory shape will never fully correspond to reality and must therefore be continuously adjusted.

This ongoing adjustment constitutes the core of what is referred to here as online control. It serves the goal of refining the afforded projection during the actual execution of the motor act. While the global projection only needs to be roughly correct, during the execution of an action all deviations must continually be absorbed and corrected based on what perception is showing in real-time.

What follows is an explanation of online control: how the inevitable deviations within the perception, during real-time execution, are mediated. This involves a dynamic interplay between the two processing streams of visual perception. The ventral stream and the dorsal stream. The mediation takes place through two autonomous processes: 1. The zigzag process, and 2. The accordion process.

How the Cortical Streams Mediate the Online Deviations

The previous clarifications demonstrate that the actual position P(0) of the pong ball at time *t*(0) solely acquires meaning within a perceptual image of an entire incoming ball trajectory shape. Just as a marble only gets meaning within the inseparable interdependency of the marble run. In the further elaboration on the cortical streams, this entanglement must be kept firmly in mind, precisely because both streams in reality operate based on one and the same indivisible projective phenomenon.

If one were to approach the perceptual processing streams from a contemporary scientific viewpoint as separate phenomena, the explanatory model of the motoric movement action would associate the ventral stream with the processing of perceptual input related to the entire incoming pong ball trajectory shape, and the dorsal stream with the processing of input related to the current position P(0) of the pong ball.
However, this perspective is fundamentally inadequate. Both the scientific literature and the critical role of stream interaction in determining the success or failure of action suggest that the two streams do not operate as strictly separate systems. Instead, the ventral and dorsal streams continuously influence one another within a double and mutual, projective cycle.
At any given moment *t*(0), the dorsal stream primarily processes all perceptions towards the precise pong ball's actual position P(0) but it remains meaningfully linked to the overall action trajectory shape. Conversely at that same moment, the ventral stream primarily processes all perceptions towards the complete incoming pong ball trajectory shape, while still retaining a relationship to the ball's precise position. The two thus guide one another within a dual reciprocal structure.
Within this structure, the ventral stream functions as the guiding system, constructing the global perceptual image of the latent, incoming trajectory. This projection serves as a reference frame against which the dorsal stream compares the actual movement of the action object (the pong ball). When the dorsal stream detects a deviation between the actual position P(0) and the projected image, this feedback is relayed back to the ventral stream. The ventral stream, in turn, regains primacy and updates the perceptual image of the latent trajectory accordingly.
Thus, a circular correction loop emerges: the dorsal stream monitors the "now," while the ventral stream continuously reconfigures the "next." Together, they enable fluid motor action within dynamically shifting boundaries. Without requiring prior precision[7].

The Cortical Streams Mediate Two Autonomous Deviation Processes: The Zigzag Process and the Accordion Process

The initial constructed perceptual image of the latent, incoming trajectory of the pong ball is explicitly not an exact projection of its future path. Such a precise prediction is factually impossible and ecologically has never been relevant within the evolutionary development of perceptual systems.
What this initial image conversely does provide is a global framework that, based on cognitive knowledge of motion behavior, allows for a rough estimate of the zone in which the pong ball is most likely to end up. This *precise global* estimation is sufficient to initiate the egocentric throwing action.

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[7] In other words, the commonly invoked dichotomy between ventral and dorsal streams, between the 'what' and 'where/how', proves to be structurally misleading. In reality, both streams operate within one and the same projective continuum, where perception and action, manifest and latent information, do not exist alongside each other as separate domains, but emerge as a single dynamic whole. This is precisely why the explanatory model does not describe two separate pathways, but rather one integrated structure in which perception and action converge. Making the *pong ball* - *pong ball trajectory* relationship an indivisible unity.

In this case, moving the paddle toward the anticipated intersection point of the two action trajectory shapes.

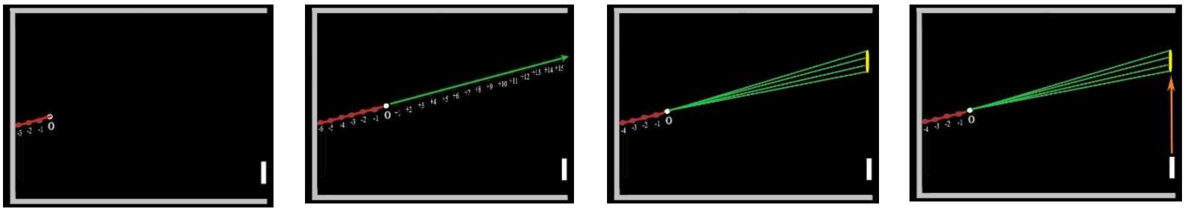

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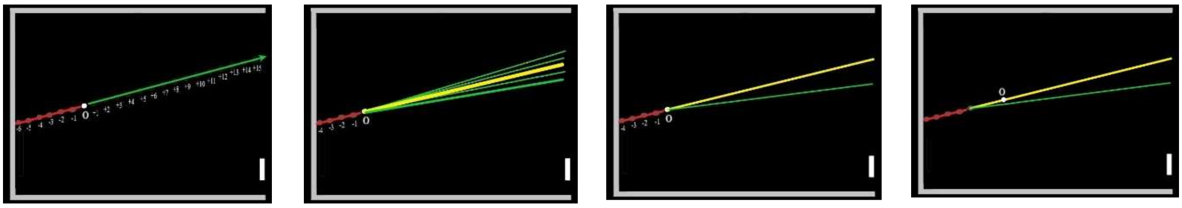
Fig.: *(Note – Deviations shown in amplified form) – The essence of early perception of the pong ball's movement lies solely in predicting an end zone, not in constructing a precise line. What matters is that, based on cognitive knowledge of motion behavior (fig. 1-2), a reliable prediction can be made of the zone in which the pong ball is likely to end up (fig. 3). The exact perceptual image c.q. the specific green line we construct is not critical as long as the egocentric movement of the paddle to that global zone can be commenced (fig. 4).*

Nevertheless, during the execution of the action, a discrepancy will inevitably arise between the perception of the pong ball's actual position P(0) at any given moment and the previously formed projective image of the pong ball's action trajectory shape. This deviation manifests itself along two autonomous dimensions, corresponding respectively to the shape (y-axis c.q. lateral deviation) and the line (x-axis c.q. longitudinal deviation) of the incoming pong ball trajectory shape. The deviations within these dimensions form the foundation of what will be referred to as the zigzag process (shape) and the accordion process (line)[8].

The Zigzag Process

When the pong ball is at position P(0) at time *t*(0) (fig. 1) our perception processes will always implicitly construct a perceptual projective image of the (latent) continuation of the manifest action trajectory shape. In a hypothetical perfect system, this projection would align exactly with the actual future motion (yellow line, fig. 2) of the pong ball.



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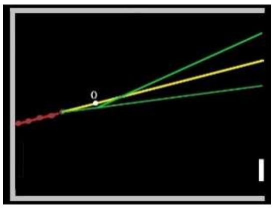
However, in reality the perceptual system does not function as a precision instrument but as an ecologically optimized system that generates only a reasonable prediction. It is therefore far more likely that you will construct a perceptual image of one of the green lines (fig. 3). A situation in which it is especially important to note that a different action trajectory will be constructed each time. Even if the pong ball were to appear in an identical manner at a future moment.

[8] In car driving or cycling without hand brakes, it becomes strikingly clear that perceptual input related to the steering system mediates only the deviations within the zigzag process, whereas perceptual input related to the pedals mediates only the deviations within the accordion process.

So, the likelihood of constructing a perceptual image that matches the yellow line is therefore virtually non-existent, but this imperfection poses no problem. The perceptual system continually corrects itself through the cortical streams. When the pong ball reaches its next position P(0) (fig. 4), the previously constructed (albeit inaccurate, yet directionally useful) perceptual image of the entire latent action trajectory is adjusted based on the new visual input.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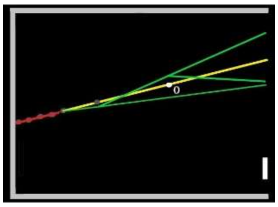
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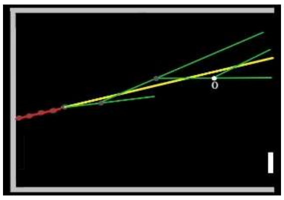
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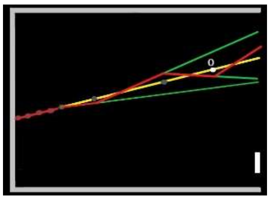
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In this way the perceived deviation between the actual position and the prediction of the pong ball leads to an updated projective image of the latent trajectory (fig. 5). This updated image is then temporarily adopted as the 'only correct future path', until the next deviation inevitably presents itself (fig. 6-7). So, in the meantime, these revised perceptual images must be treated as compelling guides for action. Even though they will never produce a perfect representation. Adjustments will always be required from one time interval to the next, simply because the future cannot be predicted with absolute precision. The successive corrections give rise to a characteristic zigzag pattern (red line, fig. 8). Which emerges from the iterative revision of the action trajectory shape along the y-axis, the shape axis, of the pong ball's movement.

The Accordion Process

Whereas the zigzag process corrects deviations in shape or width (y-axis), the accordion process[d] concerns deviations in time or length (x-axis) of the perceptual image of the latent incoming pong ball trajectory shape[9]. So, if we construct a perceptual image of a latent incoming pong ball trajectory shape we are simultaneously generating latent perceptual projections of the pong ball's temporal progression. Which we want to predict as sound as possible but will also never exactly match the real future. The pong ball will therefore always run 'ahead of' or 'behind' the implicitly expected path, and the cortical streams must correct these temporal deviations just as they do in the zigzag process described above. When the cortical streams detect a lag relative to the projected image, they must immediately generate a new perceptual image that then becomes the operative framework for the remainder of the latent, incoming ball trajectory.

The Scientific Grounding of the Function of the Cortical Streams

The explanation proposed within the explanatory model of the motoric movement action that the cortical streams mediate the online control of the pong ball's and the paddle's movement is a scientific hypothesis that will ultimately require further physiological validation. However, it is formulated in such a way that, with near certainty, one can argue that it closely reflects the actual perceptual processes, or at the very least captures their functional essence precisely. This validation rests on two pillars: 1. Scientific developments, and 2. Proof by contradiction (Reductio ad absurdum).

[9] The accordion process is difficult to visualize in animations. However, driving a car clearly demonstrates the distinction between the zigzag and the accordion process. The steering wheel solely mediates the zigzag process, while the pedals only mediate the accordion process.

Scientific Developments - The explanatory model of the motoric movement action posits that the perception of the movement of the paddle not only consist of the registration of the actual positions but is automatically supplemented by an implicit projection of future positions. This projective structure, the latent incoming pong ball trajectory shape, is visually experienced as one undivided phenomenon and forms the functional basis for any imaginable motor action.
This interpretation aligns with the broader theoretical framework of predictive coding (Friston, 2005; Clark, 2013), which posits that perception is fundamentally shaped by top-down expectations generated from prior input. The dynamic interaction between the ventral and dorsal streams can thus be understood as a bidirectional predictive cycle, in which discrepancies between expected and actual sensory input are continuously minimized through iterative updating of motor-relevant trajectory projections.
Within cognitive neuroscience, this understanding of motion perception is further supported by the distinction between the ventral and dorsal visual streams. First introduced by Goodale[e] and Milner (1992), this model identifies the ventral stream as responsible for object recognition and shape representation (the "what" pathway), while the dorsal stream functions as a visuo-motor pathway responsible for guiding real-time actions (the "where" or "how" pathway).
Although this functional dissociation remains widely accepted, more recent research highlights the degree of cooperation between these streams, particularly in situations that require anticipatory processing of object motion. Goodale[f] (2011) argues that the dorsal stream is involved not only in the control of immediate action but also in the anticipation of future object locations, thereby contributing to the construction of implicit action trajectories even in the absence of motor output.
In support of this view, Schenk and McIntosh[g] (2009) demonstrated that patients with selective damage to one of the two streams still retained the ability to generate anticipatory projections. This suggests that the capacity for visual prediction is distributed and functionally integrated across the two processing pathways and should be regarded as a general property of the perceptual system.
A particularly relevant contribution is provided by Freud, E., Behrmann, M., & Snow, J. C. (2020)[h], who showed that the dorsal stream plays a role in representing latent visual information. Their findings demonstrate that movement trajectories are processed as dynamic vector patterns, with internal continuity projections bridging over occlusions, disruptions, or temporal gaps. This is directly in line with the model's proposition that all single distinct visible moments P(0) of the pong ball are compellingly perceived as part of a larger, inferred incoming trajectory.
Monaco et al. (2019)[i], using fMRI, confirmed that both dorsal and ventral regions are involved in the anticipatory processing of visual goals. Even when no explicit motor commands were required, neural signals reflected internally simulated projections of future object trajectories. This supports the idea that the brain is structurally predisposed to identify intersections between visual projections and motor action possibilities, a core assumption of the explanatory model.
Finally, classic work by Sekuler, Watamaniuk, and Blake (2002)[j] demonstrated that visual perception of motion depends on continuous temporal projection. The visual system implicitly extrapolates trajectories from manifest positions to estimate future direction, timing, and convergence points, all of which are necessary conditions for timely and accurate motor engagement.
The described system also resonates with Gibson's notion of affordances, in which environmental features are perceived not as neutral properties but in terms of the actions they enable. In this sense, the perceived trajectory of the pong ball is not a passive spatial registration, but an active, dynamic projection of possible interactions. It constitutes an action-oriented field in which perception and motor potential are intrinsically linked.

Proof by contradiction (Reductio ad absurdum) -The explanatory model of the motoric movement action systematically integrates all relevant phenomena observed in movement science and neuroscience into a unified theoretical framework. Every empirically established aspect—ranging from predictive perceptual structures, cortical stream dynamics, *tau*-based time-to-contact estimations, to affordance-driven action coupling—finds coherent expression within this model. This integrative capacity is especially evident in its application to the game Pong, where the roles of the ventral and dorsal streams align closely with long-standing findings in visual neuroscience.
If one were to challenge this framework using a *reductio ad absurdum* strategy, by asserting, for instance, that the cortical streams function in an entirely different manner than described this would imply the need for a completely alternative explanatory model. Such a model would not only have to contradict decades of converging empirical research, but it would also need to provide a fully holistic reinterpretation of a wide range of well-documented perceptual-motor phenomena already explained by the current model.
In short, any such alternative would be required to offer a complete and ecologically viable account of motor-perceptual integration—yet no such theory has emerged in over a century of scientific inquiry. The absence of a competing explanation that matches this model's breadth and parsimony lends strong support to its plausibility. While it does not claim finality, the model presently represents the most comprehensive and empirically resonant account available.

The Movement of the Paddle

How the Perception of the Movement of the Paddle is Afforded

The Perception of the Movement of the Paddle[10]

If you want to play the game of Pong you must construct a perceptual image of a future intersection point between two latent action trajectory shapes. This involves an intersection point between: 1. A perceptual image of an action trajectory shape emerging from the motion of the pong ball, and 2. A perceptual image of an action trajectory shape emerging from the motion of the paddle. Only when these two projections converge at an intersection point they do acquire functional meaning, and only then enabling successful gameplay.

However, it is not necessary to actually play the game in order to experience these perceptual processes. One can simply observe the movements of the pong ball in isolation or independently follow the egocentric movement of the paddle across the screen. This implicitly reveals the fundamental fact that the perception of the ball's motion and that of the paddle are autonomous processes.

As long as there is no active participation in the game, the perceptual processes remain structurally separated. The movement of the pong ball, as an autonomous environmental object, appears allocentric within the visual field and represents the universal catching action. In contrast, the movement of the paddle operates within the autonomy of the organism — that is, within an egocentric action framework — and represents the universal throwing action. This distinction applies to every conceivable form of action in which the two autonomous movements can never be reconciled, as they belong to fundamentally different representational domains.

The explanation of the movement of the paddle is divided into two essential parts. The first part compels how the perception of the movement of the paddle is afforded as within Gibson's Affordances Theory. The second part clarifies how the movement of the paddle is online corrected and continuously adjusted during real-time execution.

[10] What follows is a step-by-step exposition of the projective affordance of the movement of the paddle. At each stage, however, it is essential that the analysis is continuously referred back to the full (complex and dynamic) phenomenon of which the paddle constitutes only a partial element.

The Perception of the Movement of the Paddle Encompasses Two Autonomous Foci – The Secondary Focus

The explanatory model of the motoric movement action has shown that every conceivable egocentric throwing action, such as grasping a coffee cup or moving a pointer toward an icon, requires two autonomous foci[k,l]. In which scientific evidence is provided that we must always first create a perceptual image of a latent action trajectory from the perspective of the action object c.q. the end effectors, such as the fingertips or the pointer, before we can begin any action at all[m,n]. This compels an action trajectory shape: 1. Similar to that which arises when catching the pong ball, 2. Encompassing all future positions P(0) of the paddle, and 3. Which forms the symbolic connection between the current state and the target state of the paddle (which is the intersection point between the catching and the throwing trajectories).

Respectively, the fingertips, the pointer, and the paddle perform the essence of the egocentric throwing action. However, in all three cases, it can be established that we are not actually capable of moving these action objects directly. The perception of the movement of the fingertips, the pointer or the paddle within an external action trajectory shape can only occur through internal bodily movements that reach no further than the surface of the fingertips or the outer shell of the computer mouse. These bodily movements are perceived exclusively via internal proprioception. In contrast, the action trajectory itself can only be perceived externally. Because both types of perception are strictly internal or external, they belong to irreconcilable worlds that will never overlap[11].

The task is executed through the completion of the action trajectory shape, and therefore the primary focus lies there. The internal bodily movements must be directed toward that task and are thus defined as the secondary focus. The external movement of the paddle in the game Pong can only be controlled within an action trajectory shape by internal bodily movements that reach no further than the outer surface of the computer mouse. The construction of the action trajectory shape toward the intersection point with the incoming pong ball trajectory therefore constitutes the primary focus, while the proprioceptive perceptions limited to the outside of the mouse (controller) represent the secondary focus[12].

The Perception of the Movement of the Paddle Encompasses Two Autonomous Foci – The Primary Focus

This section outlines how the perception of the paddle's movement gives rise to a projective visual image that underlies goal-directed motor action. The explanation largely follows the same structure as the account of the pong ball's movement along the incoming pong ball trajectory shape in the previous chapter.

Even after only a few lateral movements of the paddle, we are already able to accurately estimate a full action trajectory shape from side to side[13]. The paddle is constrained to move in a simple lateral

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[11] Physiological data associated with this egocentric throwing action are, due to the separation of these perceptual foci, already so fundamentally confounded that they can no longer be reliably used for drawing conclusions at the functional level.

[12] So, in every conceivable motor action, there are thus three distinct foci. Two within the egocentric throwing action, and one within the catching action. This gives rise to a triad of alignments. The secondary focus within the throwing action of the paddle is directed exclusively at the primary focus of that same throwing action, which alone enables movement along a projected trajectory. And only this primary focus of the throwing action of the paddle must then be attuned to the focus within the catching action of the pong ball, since the throwing action is the only part that can be influenced egocentrically and not the pong ball.

[13] *Precise global* as within the movement of the pong ball.

direction, and its movement speed maintains a fixed relationship with the movement speed of the computer mouse[14].

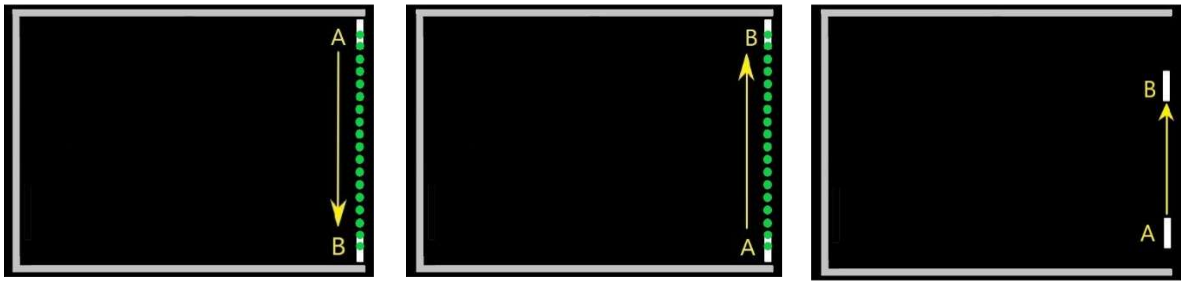

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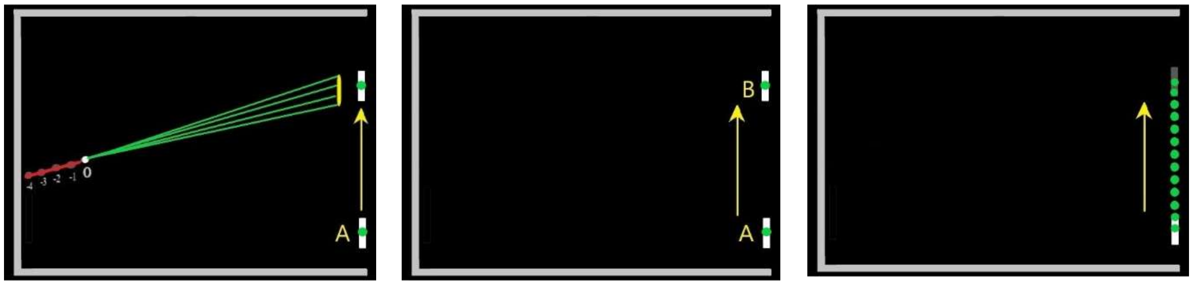
Fig.: *A paddle can only be manipulated laterally by allowing it to occupy a series of contiguous positions. Just as the pong ball functions as the action object within the catching action, the paddle serves as the action object within the throwing action. All perceptions of all action objects within any conceivable motor action must always sprout from one another and are factually constrained within a line*[15].

Regardless of how one moves the paddle from its farthest position A to the opposite extreme position B is not critical. After only a few repetitions of this lateral manipulation, we acquire sufficient cognitive knowledge to estimate how to move the paddle from one extreme to the other. As with the pong ball, it is simply a fact that any intended end position of the paddle can only emerge from a sequence of interconnected positions. This demonstrates how we can construct a perceptual image of how to move the paddle from any arbitrary point A to any arbitrary point B. This image necessarily contains two essential autonomous components: 1. The shape of the action trajectory, and 2. The temporal span in which the action object (the paddle) traverses the line, expressed in terms of time or *tau*-value.



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Once a perceptual image of a latent, incoming action trajectory shape has been distilled from the initial sequence of actual observed pong ball positions (1), we are generally able to estimate, albeit in a *precise global* way, where the intersection with the action trajectory shape of the paddle (2 and 3) will likely need to occur[16]. Determining this intersection point, or endpoint of the paddle's action trajectory, is essential for playing the game. However, it constitutes only a partial aspect of the broader perceptual

[14] This pertains to the relationship between the perception of internal bodily movements within the secondary focus towards the external action trajectory of the paddle within the primary focus.
[15] From birth to your final step, your entire body remains confined to one single line. This is a fundamental fact of motor reality that cannot be circumvented.
[16] As with the perception of the pong ball's earliest positions, none of this yet determines the level of precision that will later be required for successful action. But that has never been the purpose of these perceptual processes. The point is to initiate the action, and for that, the infinite range of possibilities must first be reduced. In fact, it can be stated that the perception of the pong ball's initial positions, along with the determination of a projected point of intersection, achieves the most significant reduction of potential outcomes.

task. At the same early stage, our perception processes also assess whether the egocentric throwing of the paddle can reach that intersection point through a continuous, uninterrupted sequence of positions.

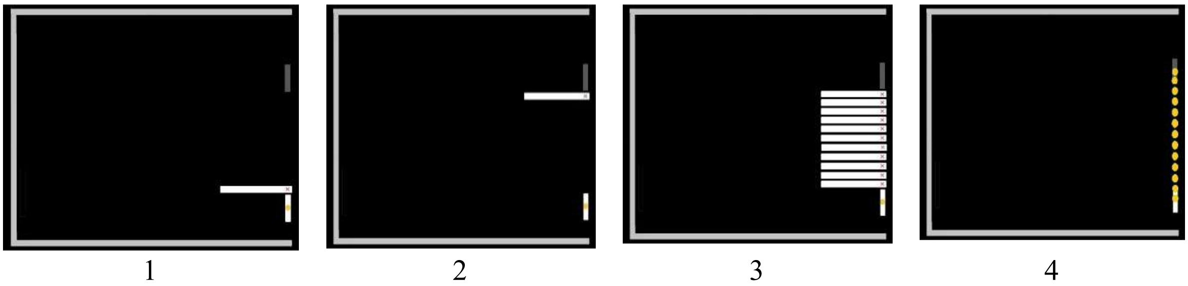


Fig.: *The explanatory model of all motoric movement actions provides scientific evidence that a perceptual image is always first constructed from the initial actual position P(0) of the paddle to the projected intersection point with the incoming pong ball trajectory shape. If a test subject were asked to move the paddle toward the intersection point solely if a successful outcome were deemed likely, the result would be as follows: if a single large obstacle is present either close to the paddle (fig. 1) or near the intersection point (fig. 2), no subject would attempt the action as part of a successful movement. That alone might not be surprising. However, if we extend this principle to any point between the paddle and the intersection, we can conclude that this logic holds for every possible position P along the way. Figure 3 illustrates this visually by showing how all these discrete points collectively form a mathematically continuous line segment shape. Proving that we consider all interconnected positions of the paddle between the original state and the future state we want to be in prior to any execution.*

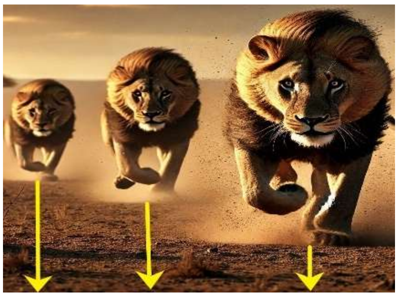
The explanatory model of the motoric movement action thus demonstrates that the affordance of an endpoint of an action trajectory shape is essential to the execution of the action. However, it also clearly shows that it is equally essential to assess whether the paddle can be guided there in one single, uninterrupted path. Together with the relevant scientific evidence, this reveals that the (perception of the) bridging process[17] is just as critical, and just as perceptually salient, as the identification and attainment of the intersection point[18].

Predictive Coding as Implicit Projective Perception

The preceding analysis demonstrates that the perception of motion is fundamentally projective in nature, as future movements must emerge from the manifest positions of the action object. Just like the perception of the incoming pong ball trajectory shape. This leads to the empirical conclusion that all future perceptions (of all future movements) must likewise emerge from prior manifest positions of the paddle. Therefore, the movement of the paddle is not perceived by the visual system as a sequence of discrete moments but rather as an implicit trajectory. In which the most probable future positions are embedded as sound as possible. So, this projected trajectory is not the result of conscious computation, but an automatically generated structure based on minimal visual input.
The explanatory model presented here demonstrates that this process is not optional or context-dependent, but structurally necessary and always operative. In fact, the model reveals that it is a

[17] The explanation of the cortical streams also clearly shows that they are engaged in guiding the paddle through each of the individual positions along the action trajectory shape, from its starting point to its endpoint.
[18] The current scientific debate revolves largely around the question of what consciousness actually entails, and considerable attention within this field is also directed at the use of eye-tracking gear. Yet both avenues fail to deliver satisfactory answers, because they overlook the fact that consciousness is also oriented toward action possibilities through continuous, empty positions P. Which are only possible precisely where there is nothing to be seen.

foundational condition for motor behavior itself: without this implicit projection, goal-directed movement would not be possible. Our perceptual organs are not passive receptors originally, but dynamic temporal comparators[o]. From an evolutionary perspective, the visual system had to detect immediately (and automatically) whether something was approaching[19], in which direction, and at what speed (whether it concerned food, a threat, or a mating partner). This evolutionary imperative led to an embedded mechanism that transforms perceived manifest motion into projected continuation: a latent trajectory shape. Thus, while the current position P(0) is always perceived as the visible front of the motion, within our perception processes it is also interpreted as the strict division between the manifest and latent part of the complete action trajectory shape.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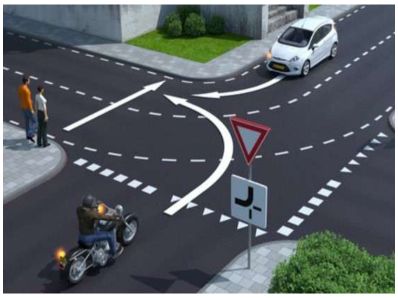
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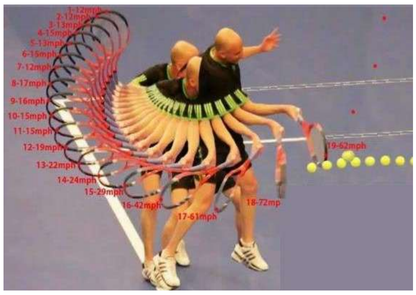
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Fig.: *The perception of confronting 'threatening' action trajectory shapes within the catching action would serve no purpose whatsoever if we were not able to respond to them with egocentric throwing actions. We may still wish to strike the lion at the right moment with the projected action trajectory shape of a rock or a spear. Or we may want to parry the incoming line segment shape with a movement that avoids contact completely. As is commonly done in traffic (except for bumper cars at a fair). Reasoning from this, one can quickly conclude that without the ability to counter an incoming pong ball or tennis ball with a suitable egocentric throwing action in the form of a projected outgoing action trajectory shape, it would be absolutely impossible to play tennis[p] or Pong.*

Traditional models of predictive coding (as in Friston and Clark) propose that the brain generates hierarchical predictions continuously updated through error correction. The model presented here shifts that perspective fundamentally. In this view predictive coding is not treated as an optional strategy or cognitive tool but as an unavoidable, automatic mechanism embedded within the perceptual organs themselves. Every perception of motion implicitly generates a projective structure in which future positions are predicted and as cognitive familiarity with specific movement patterns increases, the success of this predictive process improves accordingly.

The Paddle's Actual Position will be Reduced to One Overarching Phenomenon Within the Perception of the Complete Egocentric Paddle Trajectory Shape

When examining the perceptual processes during the egocentric throwing of the paddle more closely it becomes clear that at any given moment only one actual position P(0) at time *t*(0) of the paddle is directly visually perceived. The preceding positions P(–x) c.q. the previously manifest locations have already disappeared and the predicted future positions P(+x) c.q. the upcoming locations of the paddle are not yet present. However, it is crucial to understand that the observation of the paddle's position at P(0) compels nothing more than a perceptual fast fading snapshot within the entire continuum of actual motion representations constructed by the perceptual system.

[19] Long before conscious cognitive evaluation could establish what, exactly, was approaching, the perceptual system was already responding through predictive mechanisms.

This apparent paradox, perceiving only a single manifest moment while acting upon an entire action trajectory shape, is precisely where the explanatory model of the motoric movement action plays a central role. The current position P(0) cannot be understood in isolation; it only gains functional meaning within a projective visual representation in which both past and future positions of the action object are implicitly linked as part of a unified action trajectory shape. Solely this complete overarching phenomenon will supply the necessary requirements for successful task execution.

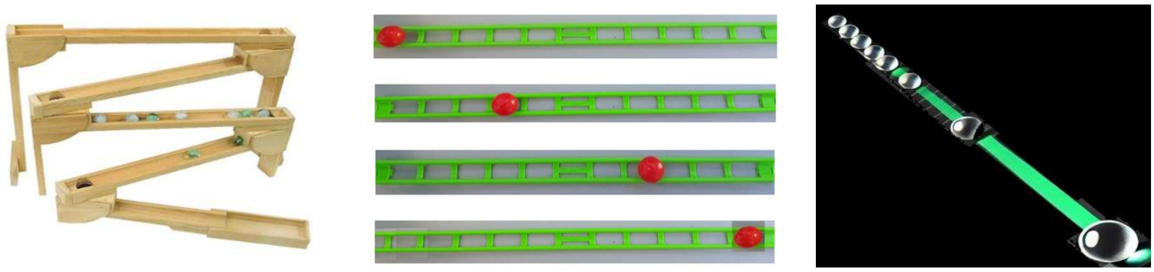

Fig.: *Perceptual images of manifest or latent positions of the action object become rarely visible, except for motor tasks like writing or pouring liquids. Yet, the explanatory model demonstrates that this implicit projective structure must be necessarily present in every goal-directed action. Without an actual position (of the marble), there is no starting point for projection and without projection (of the marble run) the marble has no functional meaning. Only through their obligatory coupling does the functional basis emerges.*

A striking metaphor is that of a marble in a marble run. It immediately illustrates that a marble without a track, and a track without a marble, are both meaningless. Only in the coupling of object and trajectory does meaning emerge. The same applies to the paddle: its position P(0) acquires perceptual value only within the implicit line structure of the entire perceptual image of the egocentric action trajectory shape toward the intersection point with the incoming pong ball trajectory shape.
In which it is crucial to understand that the observation of the paddle's position at P(0) compels nothing more than a perceptual fast fading snapshot within the broader perceptual image that explicitly consists of an estimation of future positions P(0) of that very same action object. In this sense, P(0) cannot be isolated or interpreted meaningfully without taking into account the complete latent continuation of the action trajectory shape. Meaning is generated through the unfolding of this continuity. Without it, neither the marble nor the paddle conveys anything functional or perceptible.

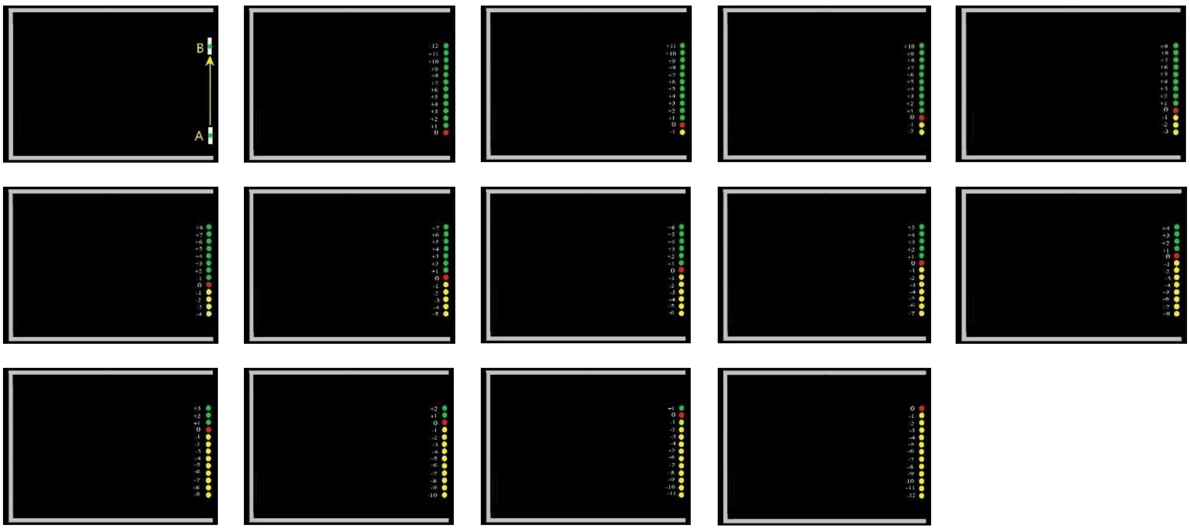

Fig.: (In the first image, the starting and ending positions of the paddle are shown. The middle of the paddle is symbolized by a green dot. To facilitate a clear explanation, only this dot is depicted in the subsequent images.) - *What applies to a classic wooden marble run also applies to the paddle within the perceptual image of the egocentric throw action trajectory shape towards the intersection point. The actual position P(0) of the paddle is consistently located at the front of the perceptual image of the manifest trajectory and thus precisely marks the exact division between what paddle positions already have been visible (the manifest trajectory) and what is still implicitly predicted (the latent trajectory). Crucially, this latent segment always logically and visually will have to emerge from the manifest part. It is not a disconnected extrapolation, but the natural continuation of an already-formed linear structure.*

This projective integration of manifest and latent positions ensures that the paddle does not appear as an autonomous object but rather as the single visible point within an implicitly constructed action trajectory shape. Or in other words, the paddle is not perceived as an isolated entity but represents the current location within a visual continuum that encompasses both direction and time. This line is not an optional addition to perception. It is perception. So, perception does not register what *is* but organizes what *can happen* based on what has already been established.

The Perception of the *Tau*-Value[q] of the Paddle Within the Egocentric Throwing Action

The explanatory model of the motoric movement action convincingly demonstrates that no separate elements occur within the perception–action coupling within the egocentric throwing action of the paddle. It definitely encompasses one undivided phenomenon. This plays a crucial role within the marble–marble run relationship. Because it is essential to perceive when and in what shape the paddle will reach the end of the egocentric action trajectory.

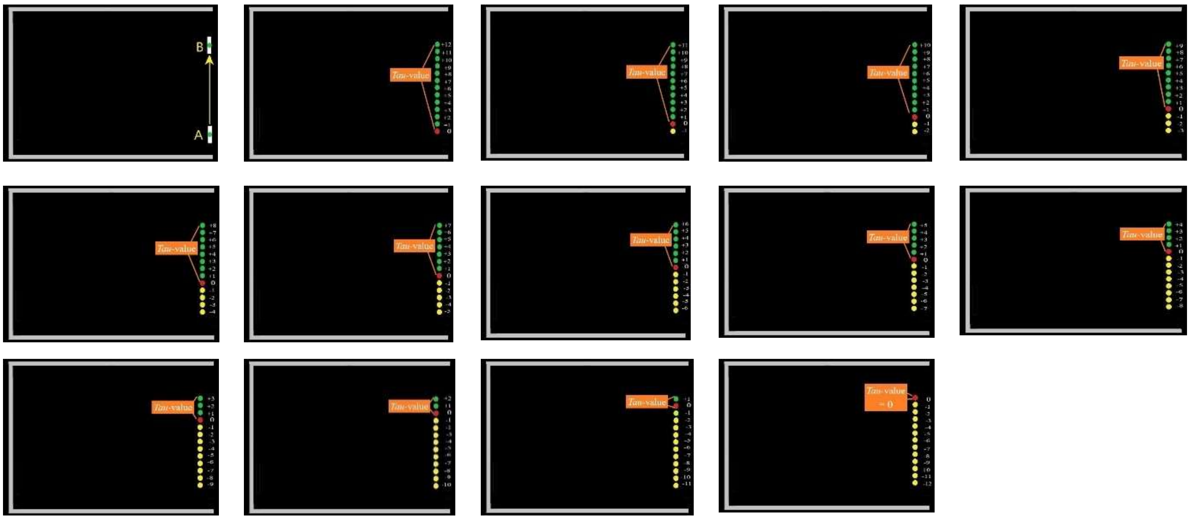

Fig.: (In the first image, the starting and ending positions of the paddle are shown. The middle of the paddle is symbolized by a green dot. To facilitate a clear explanation, only this dot is depicted in the subsequent images.) - *The tau-value, that is, the perceived distance*[20] *to the expected point of intersection with the incoming pong ball trajectory shape, decreases at a steady rate. This enables the perceptual system to accurately estimate the approaching time of impact.*

[20] Lee: "Any movement involves the closure of some kind of motion-gap between a current state and a goal state."

Because at the end of the paddle's action trajectory shape the intersection with the incoming pong ball trajectory shape must be realized. And for successful action to occur, it is essential that the paddle will arrive there *before* the *tau*-value of the pong ball's trajectory reached zero. This time-to-contact (ttc) can only be determined by perceiving the rate at which the perceptual image of the latent segment of the paddle's egocentric action trajectory converges toward zero. Which can solely happen if one has implicitly formed a coherent perceptual representation of the entire phenomenon.

The Complex Perception of the *Tau*-Value Can Be Reduced to the Simplest One-Dimensional Observation – The Ecological Justification

The preceding explanation of projective line formation, *tau*-values, and manifest and latent action trajectory structures might give the impression that perception is an ultra-demanding cognitive task and a highly intensive computational process. If such processes had to be executed with this level of computational complexity, the model would be well-nigh ecologically implausible. Our perceptual system would then constantly need to perform intricate calculations in order to initiate action.
Conversely, the opposite is true. The strength of the explanatory model lies precisely in its reduction of this underlying complexity to a single, extremely simple and visually observable phenomenon: the straightforward disappearance of a line segment toward its endpoint.

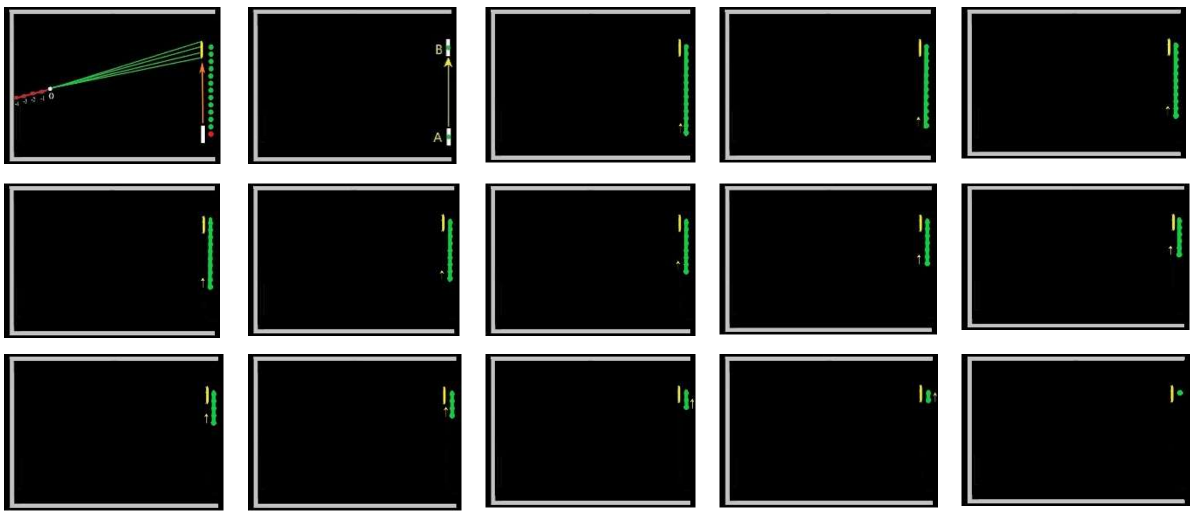

Fig.: (In the second image, the starting and ending positions of the paddle are shown. The middle of the paddle is symbolized by a green dot. To facilitate a clear explanation, only this dot is depicted in the subsequent images.) – *The highly complex process of the tau-value approaching zero can be reduced to the very simple, one-dimensional perceptual experience of a line segment progressively disappearing. Just as a boat approaching a dock gradually reduces the visible gap between the boat and the dock, the same occurs in the outgoing egocentric paddle trajectory shape. The space between the actual position of the paddle and the projected goal towards the intersection point with the incoming pong ball trajectory shape progressively disappears.*

This process requires no explicit calculation or representation. The *tau*-value, c.q. the remaining time-to-contact, manifests as the straightforward visual experience of a line segment that simply becomes progressively shorter. As with a boat slowly approaching a quay or a far jump athlete closing the distance within the run toward the take-off board. One does not see a static distance, but rather a *disappearing* distance. A vanishing gap. It is within this vanishing gap that the essence of time-to-contact is embedded, without it ever needing to be explicitly computed.
In the case of the paddle, the latent gap between the paddle and the intersection point with the pong ball is visually expressed through the *disappearance* of the line segment shape between their

respective projections. Just as the latent gap from the pong ball to that same intersection point is perceived in an identical way.

The previous clarification of the pong ball explained how the movement of the pong ball toward the intersection point likewise approaches to zero in a similarly simple manner. Thus, a highly complex dynamic system, composed of two autonomous sets of perception–action couplings, is perceptually reduced to the very simple experience of two action trajectory shapes vanishing toward a common point of intersection.

The Movement of the Paddle

How The Cortical Streams Mediate the Online Control of the Paddle's Movement

Introduction

The previous section describes how the perception of the movement of the paddle is afforded within Gibson's ecological framework. It clearly demonstrates that, based on the manifest positions of the paddle, reliable perceptual predictions can be made about future positions the paddle cannot escape. Due to the fact that the latent positions of any action object must always emerge from the manifest ones and that they are always constrained to the shape of the manifest trajectory and the speed regarding those manifest positions.

However, these early predictions represent *precise global* projective images. They are pertinently not formed to deliver an exact representation of the future action trajectory shape. As would never have been the goal within parsimonious ecologically evolving organisms. The purpose of this early prediction is solely to allow egocentric action to begin as quickly as possible and only encompasses a coarse projection of the fluctuation boundaries within which an action is most likely to unfold.

Ergo, these early estimates are merely predictions within our perception. Our subjective perception. Which may do its utmost to strive toward accuracy, but in fact never can. Even though the actual position of the action object may be perceived directly, it still remains a perception. So, the perceptual image of the future prediction of the latent part of the action trajectory shape will never fully correspond to reality and must therefore be continuously adjusted.

This ongoing adjustment constitutes the core of what is referred to here as online control. It serves the goal of refining the afforded projection during the actual execution of the motor act. While the global projection only needs to be roughly correct, during the execution of an action all deviations must continually be absorbed and corrected based on what perception is showing in real-time.

What follows is an explanation of online control: how the inevitable deviations within the perception, during real-time execution, are mediated. This involves a dynamic interplay between the two processing streams of the visual perception: the ventral stream and the dorsal stream. The mediation takes place through two autonomous processes: 1. The zigzag process, and 2. The accordion process.

How the Cortical Streams Mediate the Online Deviations

The previous clarifications demonstrate that the actual position P(0) of the paddle at time *t*(0) solely acquires meaning within a perceptual image of an entire egocentric action trajectory shape of the paddle. Just as a marble only gets meaning within the inseparable interdependency of the complete marble run. In the further elaboration on the cortical streams, this entanglement must be kept firmly in mind, precisely because both streams in reality operate based on one and the same indivisible projective phenomenon.

If one were to approach the perceptual processing streams from a contemporary scientific viewpoint as separate phenomena, the explanatory model of the motoric movement action would associate the ventral stream with the processing of perceptual input related to the entire paddle action trajectory shape, and the dorsal stream with the processing of input related to the current position P(0) of the paddle. However, this perspective is fundamentally inadequate. Both the scientific literature and the critical role of stream interaction in determining the success or failure of action suggest that the two streams do not operate as strictly separate systems. Instead, the ventral and dorsal streams continuously influence one another within a double and mutual, projective cycle.
At any given moment *t*(0), the dorsal stream primarily processes all perceptions towards the precise paddle's actual position P(0) but it remains meaningfully linked to the overall action trajectory shape. Conversely at that same moment, the ventral stream primarily processes all perceptions towards the complete outgoing paddle ball trajectory shape, while still retaining a relationship to the paddle's precise position. The two thus guide one another within a dual reciprocal structure.
Within this structure the ventral stream functions as the guiding system, constructing the global perceptual image of the latent action trajectory shape. This projection serves as a reference frame against which the dorsal stream compares the actual movement of the action object (the paddle). When the dorsal stream detects a deviation between the actual position P(0) and the projected image, this feedback is relayed back to the ventral stream. The ventral stream, in turn, regains primacy and updates the perceptual image of the latent trajectory accordingly.
Thus, a circular correction loop emerges: the dorsal stream monitors the "now," while the ventral stream continuously reconfigures the "next." Together, they enable fluid motor action within dynamically shifting boundaries. Without requiring prior precision[21].

The Cortical Streams Mediate Two Autonomous Deviation Processes: The Zigzag Process and the Accordion Process

The initial constructed perceptual image of the latent, egocentric outgoing trajectory of the paddle is explicitly not an exact projection of its future path. Such a precise prediction is factually impossible and ecologically has never been relevant within the evolutionary development of perceptual systems. What this initial image conversely does provide is a global framework that, based on cognitive knowledge of motion behavior, allows for a rough estimate of the zone in which the pong ball is most

[21] In other words, the commonly invoked dichotomy between ventral and dorsal streams, between the 'what' and 'where/how', proves to be structurally misleading. In reality, both streams operate within one and the same projective continuum, where perception and action, manifest and latent information, do not exist alongside each other as separate domains, but emerge as a single dynamic whole. This is precisely why the explanatory model does not describe two separate pathways, but rather one integrated structure in which perception and action converge. Making the paddle-trajectory relationship an indivisible unity.

likely to end up. This *precise global* estimation is sufficient to initiate the egocentric throwing action. Which in this case means moving the paddle toward the anticipated intersection point.

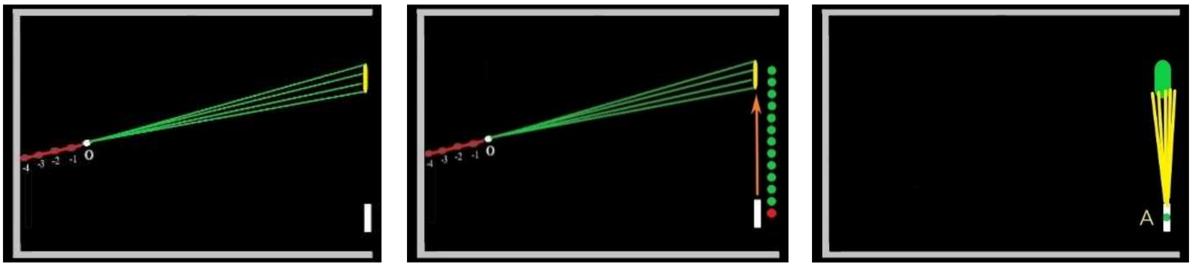

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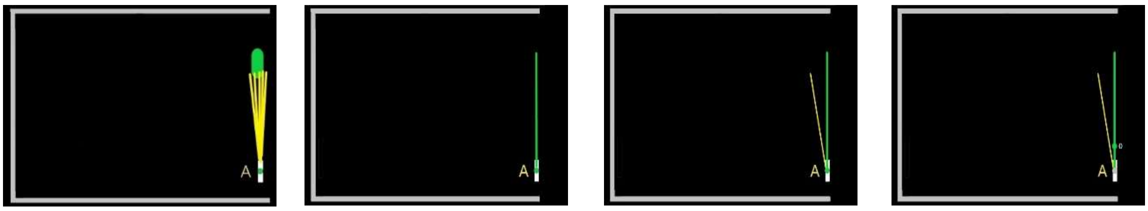
Fig.: (Note – Deviations shown in amplified form) – *The essence of early perception of the paddle's movement lies solely in predicting a global end zone (fig.3, green), not in constructing a precise line. What matters is that, based on cognitive knowledge of motion behavior, a reliable prediction can be made of the zone in which the pong ball is likely to end up (fig. 2). The exact perceptual image c.q. the specific yellow line (fig. 3) we construct is not critical as long as the egocentric movement of the paddle to that global zone can be commenced.*

Nevertheless, during the execution of the action, a discrepancy will inevitably arise between the perception of the paddle's actual position P(0) at any given moment and the previously formed projective image of the paddle's action trajectory shape. This deviation manifests itself along two autonomous dimensions, corresponding respectively to the shape (y-axis c.q. lateral deviation) and the line (x-axis c.q. longitudinal deviation) of the egocentric paddle trajectory shape. The deviations within these dimensions form the foundation of what we refer to as respectively the zigzag process (shape) and the accordion process (line)[22].

The Zigzag Process

When the paddle is at position P(0) at time *t*(0) (fig. 1) our perception processes will always implicitly construct a perceptual projective image to bridge the gap to a specified point. In a hypothetical perfect system, this projection would align exactly with the actual future motion (green line, fig. 2) of the paddle.



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However, in reality the perceptual system does not function as a precision instrument but as an ecologically optimized system that generates only a *precise global* prediction. It is therefore far more likely that you will construct a perceptual image of just one (fig. 3) of the yellow lines as shown within figure 1. A situation in which it is especially important to note that a different action trajectory will be constructed each time. Even if the paddle must shape an identical egocentric action trajectory shape.

[22] In car driving or cycling without hand brakes, it becomes strikingly clear that perceptual input related to the steering system mediates only the deviations within the zigzag process, whereas perceptual input related to the pedals mediates only the deviations within the accordion process.

So, the likelihood of constructing a perceptual image that exactly matches the green line is therefore virtually non-existent, but this imperfection poses no problem. The perceptual system continually corrects itself through the cortical streams. When the paddle reaches its next position P(0) (fig. 4), the previously constructed (albeit inaccurate, yet directionally useful) perceptual image of the entire latent action trajectory is adjusted based on the new visual input.

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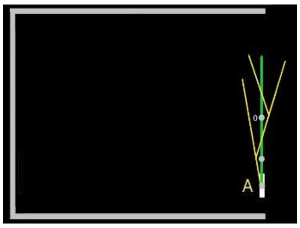

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In this way the perceived deviation between the actual position and the prediction of the paddle leads to an updated projective image of the latent trajectory (fig. 5). This updated image is then temporarily adopted as the 'only correct future path', until the next deviation inevitably presents itself (fig. 6-7). So, in the meantime, these revised perceptual images must be treated as compelling guides for action. Even though they will never produce a perfect representation. Adjustments will always be required from one time interval to the next, simply because the future cannot be predicted with absolute precision. The successive corrections give rise to a characteristic zigzag pattern (red line, fig. 8). Which emerges from the iterative revision of the action trajectory shape along the y-axis, the shape axis, of the paddle's movement.

The Accordion Process

Whereas the zigzag process corrects deviations in shape or width (y-axis), the accordion process concerns deviations in time or length (x-axis) of the perceptual image of the latent egocentric paddle trajectory shape[23]. So, if we construct a perceptual image of the action trajectory shape of the paddle we are simultaneously generating latent perceptual projections of the paddle's temporal progression. Which we want to predict as sound as possible but will also never exactly match the real future. The paddle will therefore always run 'ahead of' or 'behind' the implicitly expected path, and the cortical streams must correct these temporal deviations just as they do in the zigzag process described above. When the cortical streams detect a lag relative to the projected image, they must immediately generate a new perceptual image that then becomes the operative framework for the remainder of the latent, action trajectory shape of the paddle.

The Scientific Grounding of the Function of the Cortical Streams

The explanation proposed within the explanatory model of the motoric movement action that the cortical streams mediate the online control of the pong ball's and the paddle's movement is a scientific hypothesis that will ultimately require further physiological validation. However, it is formulated in such a way that, with near certainty, one can argue that it closely reflects the actual perceptual processes, or at the very least captures their functional essence precisely. This validation rests on two pillars: 1. Scientific Developments, and 2. Proof by contradiction (Reductio ad absurdum).

[23] The accordion process is difficult to visualize in animations. However, driving a car clearly demonstrates the distinction between the zigzag and the accordion process. The steering wheel solely mediates the zigzag process, while the pedals only mediate the accordion process.

Scientific Developments - The explanatory model of the motoric movement action posits that the perception of the movement of the paddle not only consist of the registration of the actual positions but is automatically supplemented by an implicit projection of future positions. This projective structure, the latent egocentric action trajectory shape of the paddle, is visually experienced as one undivided phenomenon and forms the functional basis for any imaginable motor action.
This interpretation aligns with the broader theoretical framework of predictive coding (Friston, 2005; Clark, 2013), which posits that perception is fundamentally shaped by top-down expectations generated from prior input. The dynamic interaction between the ventral and dorsal streams can thus be understood as a bidirectional predictive cycle, in which discrepancies between expected and actual sensory input are continuously minimized through iterative updating of motor-relevant trajectory projections.
Within cognitive neuroscience, this understanding of motion perception is further supported by the distinction between the ventral and dorsal visual streams. First introduced by Goodale and Milner (1992), this model identifies the ventral stream as responsible for object recognition and shape representation (the "what" pathway), while the dorsal stream functions as a visuo-motor pathway responsible for guiding real-time actions (the "where" or "how" pathway).
Although this functional dissociation remains widely accepted, more recent research highlights the degree of cooperation between these streams, particularly in situations that require anticipatory processing of object motion. Goodale (2011) argues that the dorsal stream is involved not only in the control of immediate action but also in the anticipation of future object locations, thereby contributing to the construction of implicit action trajectories even in the absence of motor output.
In support of this view, Schenk and McIntosh (2009) demonstrated that patients with selective damage to one of the two streams still retained the ability to generate anticipatory projections. This suggests that the capacity for visual prediction is distributed and functionally integrated across the two processing pathways and should be regarded as a general property of the perceptual system.
A particularly relevant contribution is provided by Freud, Behrmann, and Snow, (2020), who showed that the dorsal stream plays a role in representing latent visual information. Their findings demonstrate that movement trajectories are processed as dynamic vector patterns, with internal continuity projections bridging over occlusions, disruptions, or temporal gaps. This is directly in line with the model's proposition that all single distinct visible moments P(0) of the paddle are compellingly perceived as part of a larger, inferred egocentric outgoing trajectory.
Monaco et al. (2019), using fMRI, confirmed that both dorsal and ventral regions are involved in the anticipatory processing of visual goals. Even when no explicit motor commands were required, neural signals reflected internally simulated projections of future object trajectories. This supports the idea that the brain is structurally predisposed to identify intersections between visual projections and motor action possibilities, a core assumption of the explanatory model.
Finally, classic work by Sekuler, Watamaniuk, and Blake (2002), demonstrated that visual perception of motion depends on continuous temporal projection. The visual system implicitly extrapolates trajectories from manifest positions to estimate future direction, timing, and convergence points, all of which are necessary conditions for timely and accurate motor engagement.
The described system also resonates with Gibson's notion of affordances, in which environmental features are perceived not as neutral properties but in terms of the actions they enable. In this sense, the perceived trajectory of the paddle is not a passive spatial registration, but an active, dynamic projection of possible interactions. It constitutes an action-oriented field in which perception and motor potential are intrinsically linked.

Proof by contradiction (Reductio ad absurdum) - The explanatory model of the motoric movement action systematically integrates all relevant phenomena observed in movement science and neuroscience into a unified theoretical framework. Every empirically established aspect—ranging from predictive perceptual structures, cortical stream dynamics, tau-based time-to-contact estimations, to affordance-driven action coupling—finds coherent expression within this model. This integrative capacity is especially evident in its application to the game Pong, where the roles of the ventral and dorsal streams align closely with long-standing findings in visual neuroscience.

If one were to challenge this framework using a *reductio ad absurdum* strategy, by asserting, for instance, that the cortical streams function in an entirely different manner than described this would imply the need for a completely alternative explanatory model. Such a model would not only have to contradict decades of converging empirical research, but it would also need to provide a fully holistic reinterpretation of a wide range of well-documented perceptual-motor phenomena already explained by the current model.

In short, any such alternative would be required to offer a complete and ecologically viable account of motor-perceptual integration—yet no such theory has emerged in over a century of scientific inquiry. The absence of a competing explanation that matches this model's breadth and parsimony lends strong support to its plausibility. While it does not claim finality, the model presently represents the most comprehensive and empirically resonant account available.

The Playing of the Game of Pong

Introduction

The perceptual processes involved in tracking the movement of the pong ball and the movement of the paddle compel two completely autonomous phenomena and have therefore been assessed in two distinct sections. Their movements will only acquire functional relevance once an egocentric intention is formed to engage in the game of Pong which requires the construction and execution of an intersection point between the action trajectory shape of the paddle and the action trajectory shape of the pong ball. The preceding sections mainly address those autonomous phenomena. In this section conversely shifts the focus to the playing of the game, specifically to the demands it places on human cognitive and perceptual functioning in order to be played successfully. To this end, we will first define the standard gameplay parameters, and subsequently demonstrate how empirical deviations from these parameters elicit perceptual responses that align precisely with the explanatory predictions of the proposed model.

Only a Perceptual Image of an Intersection Point Establishes a Relationship Between the Pong Ball and the Paddle

The preceding sections have provided a comprehensive scientific explanation showing that the game of Pong can only be played by constructing a latent perceptual image of an intersection point between two autonomous line segment shapes. So, outside of this intersection, the motion of the pong ball and the movement of the paddle each follow their respective action trajectory shapes as fully autonomous processes. Which autonomy of course applies to their perceptual processing as well.

Within the context of gameplay, these two movement paths solely become related only when a convergence point is constructed between their respective trajectories. It is at that moment that both paths acquire a shared endpoint and, consequently, a functional relationship. Without such an intersection, the motion of the ball and the movement of the paddle remain entirely separate phenomena.

A Triad of Three Autonomous Foci

The perceptual processing of the pong ball's movement corresponds to the universal mechanism of catching the environmental object during any goal-directed action. In contrast, the perception of the paddle's movement reflects the universal explanation of the egocentric throwing action within such actions.

The latter egocentric throwing action comprises two autonomous foci, as the paddle can only be moved along an external action trajectory through internal bodily movements that extend only as far as the outer surface of the mouse (or controller). The paddle's motion along its external trajectory is primarily perceived visually, while the movement of the hand operating the mouse is perceived

exclusively through proprioception[24] towards the outer casing of the mouse. These two domains can never overlap, as they belong to fundamentally different realms — internal versus external.
The bodily movements that extend only to the outer surface of the mouse remain internal in nature, yet they must be directed toward the external action trajectory of the paddle. The primary focus within the egocentric throwing action therefore encompasses the guidance of the paddle along its action trajectory toward the projected point of intersection. Meanwhile, the secondary internal focus, which controls the movement of the mouse, must in turn be oriented toward that primary focus. Both of these foci, which together constitute the egocentric throwing action, must ultimately be oriented toward the catching process in relation to the pong ball. After all, we will never be capable of influencing the trajectory of the pong ball, whereas the trajectory of the paddle conversely can be manipulated.

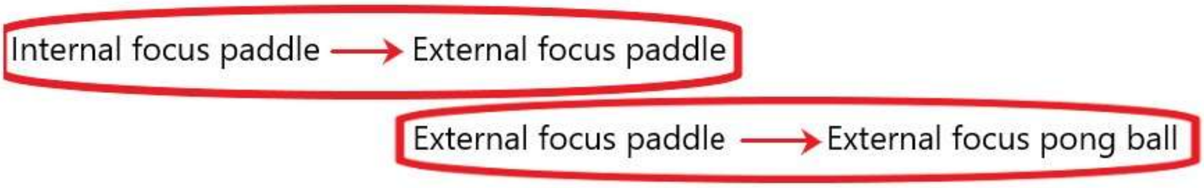

Fig.: *It is essential to note that proprioceptive awareness of the mouse is exclusively related to the paddle's action trajectory and not to the perception of the pong ball's movement. Furthermore, it is crucial to recognize that although the main goal is to align the paddle's trajectory (the primary focus) with the oncoming ball, there is always proprioceptive monitoring of the hand's movement toward the mouse. This detail forms the scientific novelty of the model which shows that visual attention can shift before a motor action has been fully completed* (Hayhoe and Land - 2001[r]). *This phenomenon will be discussed in greater depth later.*

Accordingly, a triadic structure of foci emerges. The secondary focus within the egocentric action must remain directed toward the primary focus, while the same primary focus must be fully directed at the movement of the pong ball within its incoming ball trajectory shape.

How the Three Autonomous Foci Are Perceived During the Gameplay of Pong

The explanatory model of the motoric movement action provides scientific evidence for the claim that each of the three foci can be perceived proprioceptively. As this principle may be conceptually demanding within a computer task, it will first be illustrated using a more ordinary motor task: unlocking a door with a key[s].
When unlocking a door in complete darkness, we can perceive whether the lock is shifting, and where exactly the keyhole is located, by placing the non-key hand against the lock (focus catch action). That task is not complicated and is it much more important that the placing of the non-key hand against the lock enables the creation of an action trajectory via proprioceptive awareness between the keyhole and the tip of the key (primary focus throw action). Which then enables to proprioceptively execute the *tau*-regulated motion along the action trajectory shape with proprioceptive awareness toward the key's head (the secondary focus) which we are solely capable to manipulate motorically.
When we now execute the same task in daylight, the essence of this entire explanation becomes apparent. The position of the lock can now be perceived visually, and thus the action trajectory between the

[24] Contemporary scientific discourse still largely assumes the existence of a single, unified focus within motor actions. However, the explanatory model presented here demonstrates that the egocentric movement of the paddle must be governed by two autonomous processes operating simultaneously within the brain. This observation alone reveals that the underlying neural activity must involve at least two distinct and complex subsystems.

key and the lock can also be constructed visually. Which successful completion within the primary focus of the egocentric throwing process can also occur entirely through visual perception.

The key novelty, however, is that although visual perception largely takes over, proprioceptive perception, what becomes so evident during the night, does not disappear. It remains present alongside vision, in whatever hybrid form the task may take. So, even in daylight, we continue to proprioceptively track and mediate the movement of the key along the action trajectory. Or in other words, we will always remain to bodily sense (feel) how the key is moving along the action trajectory shape.

The same principle applies in the game of Pong. The movement of the ball can only be perceived visually, while the secondary focus within the egocentric throwing action, directed toward the outer surface of the computer mouse, can only be perceived proprioceptively through internal bodily movements. This should by now be evident.

However, it is much harder to grasp that the movement of the paddle, although primarily mediated by vision, is also continuously monitored proprioceptively. Just like in the key-and-lock example, we always retain a bodily sense of how the paddle moves along its trajectory. This is especially remarkable, given that the paddle on the screen provides no haptic feedback whatsoever. Conversely the proprioceptive awareness which is clarified in here does not take place at the location of the paddle, as it would in more ordinary actions, but rather at the level of the hand in contact with the mouse.

In addition to perceiving the external surface of the mouse via the secondary focus, we also perceive the movement of the mouse itself. Under standard settings, the mouse moves along a linear segment that corresponds to the linear segment of the paddle's movement on the computer screen. Although the movements are not physically identical, they maintain a fixed relational correspondence. Thus, in addition to proprioceptively sensing the outer surface of the mouse, we also proprioceptively feel the movement of the mouse along a trajectory that corresponds to the paddle's trajectory on the screen.

The Catching Process Encompasses an Optimization Process

Catching the pong ball within its incoming trajectory is not an exact process. While the game of Pong allows for highly precise predictions about the global course of the action, these predictions will inevitably deviate from the actual positions P that will ultimately become manifest. This applies not only to the initial segment of the pong ball's trajectory but also to its final phase. However, as long as any remaining deviations fall well within the spatial extent of the paddle, successful interception remains unaffected.

A similar principle can be observed when reaching for a small light switch with the hand. As the hand moves along its action trajectory shape toward the switch, it also will naturally deviate at every moment and must therefore be continuously mediated. However, due to the fact that the aperture of the hand is many times larger than the switch, any final deviations can easily be absorbed within the hand's opening, preventing failure. The switch can't escape the hand and so this task can be completed reliably despite ongoing micro-deviations.

As a result, this type of task requires only minimal visual guidance. Vision is used to define the action trajectory and to initiate the movement, after which the process can be governed almost entirely by proprioceptive perception. In the case of Pong, however, the player is engaged in an enjoyable, attention-driven task. As such, visual attention is likely to remain focused on both the ball and the paddle throughout gameplay. Nevertheless, this visual focus does not need to be maintained with full intensity at all times. Proprioceptive monitoring remains constantly active in a hybrid supportive role, and thus continues to contribute meaningfully to successful gameplay.

The Complex Explanations Can Be Reduced to Two Simple Vanishing Lines

The explanatory model of the motoric movement action readily acknowledges that the description of all functional perceptual processes is so complex that it could never be ecologically justified unless the two autonomous phenomena could be reduced to much simpler perceptual units. Conversely, the model convincingly demonstrates that both the motion of the pong ball and the movement of the paddle can indeed be reduced to the simplest perceptual form. They can be understood as the perception of a gradually vanishing gap toward the intersection point of the two action trajectory shapes.

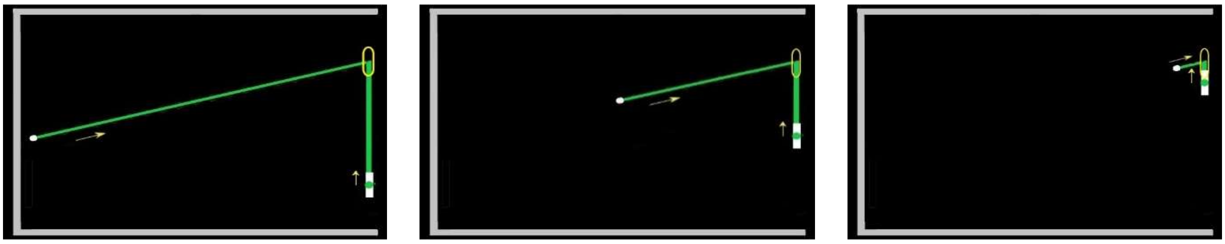

Fig.: *The initial positions of the pong ball give rise to a perceptual image of a latent incoming ball trajectory shape, which in turn quickly enables the formation of a perceptual image of a potential intersection point with the movement of the paddle along an egocentric action trajectory shape. This intersection point may be represented either as a specific location or as a broader spatial zone (indicated in yellow). - The perception of the motion of both the ball and the paddle as they converge toward this intersection point involves an explanatory framework that is, at first glance, too complex to be reconciled with an ecological perspective. However, this explanation can be reduced to two simple one-dimensional phenomena. In line with the concept of the gap introduced by D.N. Lee in his tau-coupling theory, it suffices to observe how a distance disappears. Much like watching a ship approaching the dock or a long jump athlete completing the run-up towards a take-off board as the intervening space gradually reduces to zero.*

Playing Pong Within the Recognizable Parameters of the Game

The validity of the explanatory model of the motoric movement action is strengthened when it can be empirically demonstrated that perceptual responses behave in accordance with the model's predictions when specific parameters of the game are manipulated. This is best achieved by first defining the baseline situation that reflects the recognizable parameter values of traditional Pong gameplay. Starting from this reference point makes it easier to interpret the effects of any subsequent changes.

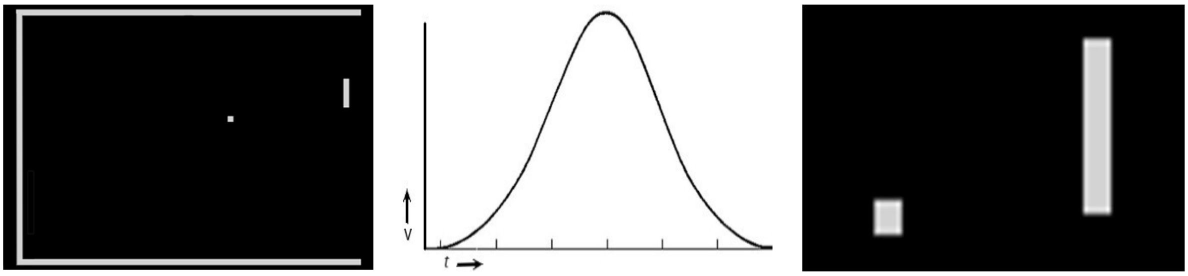

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Fig.: *A recognizable field aspect ratio (fig. 1), a bell-shaped velocity curve (fig. 2), and a recognizable ball-to-paddle size ratio (fig. 3).*

The recognizable parameters of the game of Pong include the following:

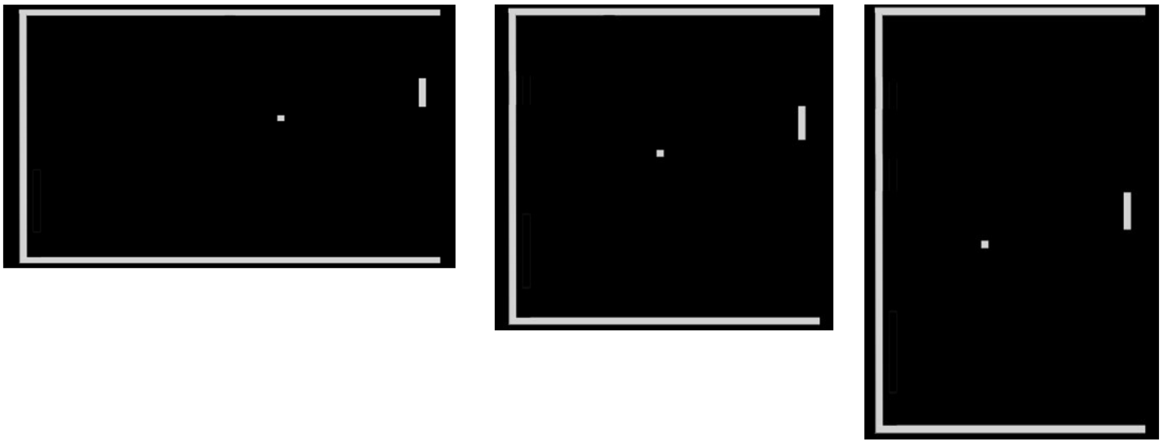
1. **The length-to-width ratio of the pong field**. The length of the field over which the pong ball moves from side to side is greater than the width of the field over which the paddle can move laterally.
2. **The ratio of the pong ball's velocity to the paddle’s velocity.** The Pong ball moves at a speed that allows the player to comfortably move the paddle across the entire range of the playing field.

After a short initiation phase, the paddle can be accelerated and then decelerated in such a comfortable way that it can come to a precise stop at the anticipated intersection point with the incoming trajectory of the ball. This reflects a *bell-shaped trajectory velocity profile*. Therefore, the process of bringing the paddle's *tau*-value to zero can be easily maintained within the temporal bounds set by the *tau*-value of the pong ball.

3. **The size ratio between the pong ball and the paddle.** If the diameter of the pong ball is taken as one unit (x), then in most standard implementations of the game, the paddle has a length of approximately 4 to 8 units (4–8x). This size ratio ensures that final deviations near the point of interception can be absorbed within the spatial extent of the paddle.

The Length-to-Width Ratio of the Pong Field

Under the standard parameters of Pong, the vertical length of the playing field exceeds its horizontal width. So, when a normal pong ball velocity is involved, the resulting incoming ball trajectory shape provides sufficient time to move the paddle toward the intersection point of the two trajectories. Then the *tau*-ratio of the paddle can be maintained well within the *tau*-ratio of the pong ball.



However, if the length-to-width ratio shifts in favor of the width, at a constant velocity of the pong ball, the *tau*-value of the paddle will come under increasing pressure. The paddle must be moved across a greater distance to reach possible intersection points, while the pong ball simultaneously travels a shorter path, leaving progressively less time for successful interception.

The Ratio of the Pong Ball's Velocity to the Paddle's Velocity

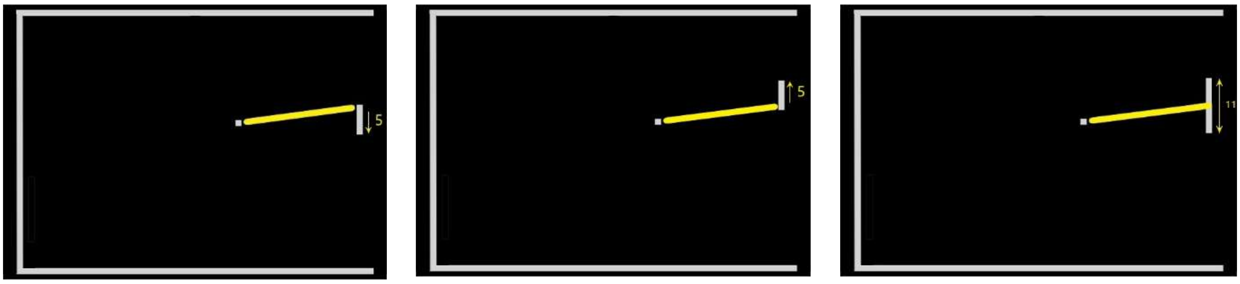
Under normal conditions, the pong ball moves at a speed that allows the paddle to reach the intersection point with ease and thus with high certainty. Within there the velocity profile of the paddle typically follows a familiar pattern as in many motor actions. At the outset, the intersection point must first be reliably identified, and the movement initiated. The paddle can then accelerate, since there is still a relatively long distance to cover where definitely no interception will occur. Conversely, when the paddle approaches the region where interception is expected to take place, the player must begin to decelerate in time to bring the paddle to a complete stop within the zone of convergence. Accurate deceleration is essential to the success of the action and so requires sufficient time.
This provides the characteristic bell-shaped velocity profile, which is commonly observed within many motor actions[25]. In which can be noticed that this bell-shape comes under pressure when the velocity of the pong ball increases. If the *tau*-value of the pong ball becomes so short that the paddle can only just reach the intersection point in time, then smooth deceleration of the paddle becomes

[25] Solely motor actions that require a crescendo at the endpoint, such as clapping hands, swatting a mosquito on the head, or engaging in combat, will bypass deceleration at the end of the egocentric action trajectory.

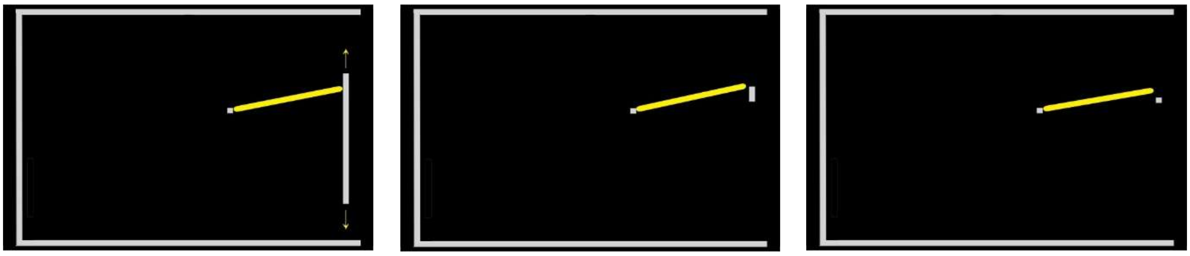
impossible. This significantly increases the likelihood of failure, since deviations in the visual perception of the pong ball's incoming trajectory can no longer be sufficiently compensated for by paddle movements.
When the speed of the pong ball exceeds a certain threshold, it becomes physically impossible for the paddle's *tau*-value to converge within the increasingly brief *tau*-value of the ball. At this point, the speed of the environmental object surpasses the limits of human perceptual and motor capacities[26].

The Size Ratio Between the Pong Ball and the Paddle

The size ratio between the pong ball and the paddle varies across different game implementations. In this analysis, a representative ratio of 1:6 is adopted. This means that the pong ball fits six times into the paddle's length. This specific proportion serves as a useful standard for exploring how spatial tolerances and perceptual error margins influence the dynamics of interception within the game. So, under standard conditions, this ratio results in eleven (11) spatial units within which the paddle's final position can still successfully intercept the pong ball. The tolerance range for intercepting the ball is thus nearly double the paddle's length, following the formula: $2n - 1$, which in this case results in $(2\times6)-1 = 11$ units. This wide margin allows visual perception to easily observe the incoming pong ball trajectory shape c.q. allows the visual processing mechanisms to absorb deviations within that action trajectory shape well within the spatial extent of the paddle, ensuring a high success rate.



With each additional unit added to the paddle's size, the level of difficulty decreases by a value of 2. This is clearly observable. When the paddle becomes proportionally large relative to the catching zone, it becomes almost impossible to miss the pong ball. At that point, visual monitoring becomes less necessary, and proprioceptive perception alone is often sufficient to guide the paddle to the correct position.



Conversely, the level of difficulty increases with a value of 2 with every unit decrease in paddle size. As the paddle becomes smaller, multiple perceptual and cognitive systems come under strain. Especially the cortical processing of the perceptions. The perceptual predictions of the ball's trajectory will remain the same, but the ability to respond effectively to unexpected variation will increasingly diminish.

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[26] Consider also the difference between, for example, an approaching cyclist, a car on the highway, or a Formula 1 race car. Similarly, compare the perceptual demands of an incoming tennis ball, an arrow in flight, or a bullet travelling at supersonic speed.

So, when the paddle is reduced to one single unit in size, continuous visual attention becomes essential. Which no longer allows for a relaxed, hybrid reliance on both visual and proprioceptive processes. There will no longer be a zone of intersection points present but only one single critical point, that cannot be accurately predicted in advance. Which, at moderate ball speeds, may still be employed effectively, but as ball speed increases, the game becomes less about skill and more about chance.

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