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NEURAL MECHANISMS OF ORGANISM-DEPENDENT AFFORDANCES: THE XPLR-XPLT MOVEMENT SPECTRUM

Abstract. Affordances face definitional chaos. Ecological psychologists disagree about their ontological status (dispositional properties vs. organism-environment relations) and about their processing mechanisms (direct perception vs. representational inference). The only characteristics researchers agree on are that affordances are organism-dependent and action-related, yet actions escape definitions across ecological psychology, philosophy, and neuroscience. After reviewing definitions of actions across these three fields, this article operationalises actions as observable movements varying systematically from exploratory (XPLR) to exploitative (XPLT). Behavioural evidence shows that movements become automated across training, with decreasing reaction times and reduced variability. Neural evidence reveals cortical and subcortical networks that correlate with the automation of movements with training. The movement spectrum accommodates both dispositional and relational ontologies by specifying how organism-dependence operates through neural reorganisation. Orthogonally, the XPLR-XPLT spectrum applied to movements at immediate timescales addresses the sensorimotor perception-movement loop. Whether this is direct or representational remains an open question. This work provides a mechanistic specification for organism-dependence compatible with competing camps.

Keywords: affordances, ecological psychology, motor learning, movement automation, exploration-exploitation, direct perception, predictive processing, representations.

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Introduction

Ask three ecological psychologists what affordances are and you'll get five answers. Gibson introduced the concept in 1979 to describe the environments that offer organisms opportunities for action. Since then, affordances have proliferated into mental, social, cognitive, and cascading affordances. Norman appropriated the term for design. Two main divisions are processing mechanism (are affordances direct or representational?) and ontological status (are affordances properties or relations?) Malo & Prié (2024) documented the result: there is no theoretical consensus on what affordances are. Baggs & Chemero (2019, p. 9) put it bluntly: "no one knows what affordances are anymore."

There are, however, two features that everyone agrees on when discussing affordances. They functionally relate to actions and are organism-dependent. A staircase affords climbing for humans, not snakes. However, ecological psychology characterises affordances through their relationship to actions but does not define actions independently. Gibson (1979/2014) uses "action" extensively throughout his affordance chapter without providing an explicit definition. Turvey (1992), Stoffregen (2003), and Chemero (2009) continue this pattern. Actions are a primitive term used circularly: affordances are possibilities for action, actions actualise affordances, and neither term receives independent specification. Yet if affordances depend on actions, and actions remain undefined in ecological psychology, then perhaps this is why everyone agrees that affordances relate to actions: actions in ecological psychology can be understood in multiple ways.

Perhaps philosophy of action might provide clarity, but I found no coherent definition of actions there. Depending on the philosophical theory, actions involve or not intentions, decisions, or causality. Since conceptual analysis yields no consensus, I turn to empirical operationalisation. Neuroscientists treat action as a unified construct, yet actions combine movements with decisions about movements. Existing frameworks fragment because they group non-equivalent phenomena under shared labels, creating false theoretical unity. Section 1 focuses on a literature review to define affordances and actions.

The only starting point I identified is that, in a broad sense, affordances functionally relate to actions. How organisms perform actions determines which affordances exist. Performing actions is observable and measurable experimentally. Hence, in Section 1.5, I operationalise actions as movements. Specifically, I define actions as observable biomechanical movements and their neural correlates[1]. Movements are observable, measurable,

and have neural correlates. Decisions require additional theoretical commitments. I follow methodological pragmatism by establishing what can be measured before adding what must be inferred. Movements vary systematically from exploratory (XPLR) to exploitative (XPLT), from flexible to automatic. This motor automation appears robust across paradigms: finger sequences show reaction-time reductions, pianists reduce keystroke variability over months, and swimmers shift from drag-dependent to efficiency-dependent propulsion across training seasons.

Given my operationalisation of actions as movements and my characterisation of movements on the XPLR-XPLT spectrum, I propose XPLR affordances (features that invite flexible movements) and XPLT affordances (features that invite automated movements). The same climbing route presents XPLR affordances to novices unsure about each handhold, and XPLT affordances to experts executing automatically. The wall hasn't changed. The organism's movement repertoire and its neural implementation have.

After defining the ground terms in Section 1, I demonstrate the XPLR-XPLT spectrum through neural mechanisms implementing movement automation in Section 2. Section 3 shows the compatibility of this movement-level evidence with both ends of the dispositional-relational debate about the ontological status of affordances. Section 4 confronts the level conflation problem: by focusing on movements, I bracket intentions and plans, revealing why existing frameworks fragment. I leverage this conflation to address direct-representational debate in ecological psychology and provide additional neuroscientific evidence that either camp can account for to move forward.

1. Affordances and Actions

Gibson's concept of affordances transformed ecological psychology but never achieved definitional stability. Theorists debate the ontological status of affordances (as environmental properties vs. organism-environment relations). This section documents the chaos and converges into a functional consensus as both sides agree that affordances functionally relate to actions. Critically, ecological psychology does not define actions independently, creating circular interdependence: affordances characterised through actions, actions understood through affordance actualisation, neither term independently specified. Nevertheless, this functional connection between affordances and actions provides the foundation for neuroscience's contribution.

1.1. The Ontological Chaos: What Are Affordances?

The ambiguity about ontological status started with Gibson himself. His canonical definition describes affordances as what the environment "offers, provides, or furnishes" the animal (Gibson, 1979/2014, p. 119), treating affordances as objective environmental features. However, within the same chapter, he writes that "an affordance is neither an objective property nor a subjective property; or it is both if you like... It is equally a fact of the environment and a fact of behavior" (Gibson, 1979/2014, p. 121). Gibson oscillated between presenting affordances as properties "out there" and as organism-relative relations. This ambiguity foreshadowed the later dispositional-relational split.

Subsequent theorists formalised different aspects of Gibson's ideas. Turvey (1992) developed the "out there" stance from page 119 into dispositional properties: real possibilities constituted by environmental features that actualise when meeting complementary organism capabilities. Chemero (2003) and Stoffregen (2003) developed the relational stance from page 121, proposing that affordances are emergent properties of animal-environment systems. Stoffregen (2003, p. 115) argued that affordances "do not inhere in either the environment or the animal," explicitly challenging Turvey's dispositional account. Kirlik (2004, p. 73) noted that Stoffregen's definition "lacks any substantive linkage to the 'opportunity for action' notion", revealing disagreement between the camps.

The terminology proliferated beyond Gibson's original scope. Researchers introduced mental, social, cognitive, cascading affordances (Rietveld & Kiverstein, 2014; Van Dijk, 2021). Chong & Proctor (2020) note "there is no singular definition of affordances and discussions of the concept do not strictly adhere to the theoretical work conducted by Gibson." Malo & Prié (2024) identify three sources of instability: originary ambiguity in Gibson's inconsistent descriptions, theoretical proliferation through the dispositional-relational debate, and drift from Gibson as contemporary research becomes "less and less concerned with Gibsonian legacy." Malo & Prié (2024, p. 2) state explicitly: "there is currently no theoretical consensus on what affordances are, and no theoretical solution seems at hand." Baggs & Chemero (2019, p. 9) conclude: "no one knows what affordances are anymore."

Nevertheless, accounts converge on functional agreement. Ecological psychology treats affordances as organism-dependent, action-related properties that organisms directly perceive (Chemero, 2003, 2009; Gibson, 1979/2014; Stoffregen & Wagman, 2025). The same environmental feature offers different affordances to different organisms.

1.2. Actions as a Primitive Concept in Ecological Psychology

Irrespective of the ontological position on affordances, both sides agree on two properties. First, affordances depend on the organism. They are not universal physical features but involve possibilities relative to specific capabilities, body configurations, and action repertoires (Chemero, 2009; Gibson, 1979/2014; Warren, 1984). Second, affordances functionally relate to actions. For example, Norman's (2013) design-oriented adaptation narrowed the concept for practical application while preserving its action-relatedness.

This functional consensus appears across theoretical positions. Gibson's formulations emphasized what environments offer or furnish for organisms. Michaels & Carello's (1981, p. 42) influential phrasing captured this: "humans do not perceive chairs, pencils, and doughnuts, they perceive places to sit, objects with which to write, and things to eat". Contemporary definitions maintain this action-oriented characterisation while varying in ontological commitment (Blau & Wagman, 2022; Rietveld et al., 2018). The field agrees that affordances functionally relate to an organism's actions.

The issue is that ecological psychologists do not define actions. Gibson (1979/2014) uses "action" extensively throughout Chapter 8 without providing an explicit "action is X" statement. Actions function as a primitive concept, understood implicitly through usage rather than specified explicitly through definition. When Gibson writes that affordances are "possibilities for action" or "opportunities for action," he assumes a shared understanding of what actions are without defining them.

This pattern continues across ecological psychology. Turvey (1992) discusses affordances extensively in relation to "prospective control" and "effectivities" but treats action itself as unproblematic. Stroffegen (2003, p. 125) uses the term "behaviour" instead of "action" to refer to "the conjunction of complementary affordances and intentions or goals", which is, however, circular. Chemero (2009) frames affordances as "relations between abilities to perceive and act and features of the environment", but does not specify what constitutes an action beyond these relational contexts. The circularity is systematic: affordances are characterised through actions/behaviours, actions/behaviours are characterised through affordance actualisation, neither receives independent specification. What *exactly* is an action?

The absence creates compounding instability. If affordances are "possibilities for action" and we do not know what actions are, then we do not know what these possibilities are for. If affordances are "organism-dependent" through action repertoires, and action repertoires remain un-

specified, then the nature of organism-dependence remains unclear. The functional relationship between affordances and actions holds despite this circularity, but relating two undefined concepts cannot provide definitional clarity for either.

1.3. Actions in Philosophy

Philosophy might resolve what ecological psychology left undefined. The field has addressed action systematically since the early 20th century, with sustained attention from phenomenology, analytic philosophy, pragmatism, and ordinary language traditions. Philosophy has debated action for over a century. However, they reached no convergence.

The dominant analytic tradition treats actions as bodily movements caused by mental states. Davidson (1963) formulated the canonical version: actions are movements caused by belief-desire pairs that rationalise them. This causal theory frames most contemporary philosophy of action and provides the foundation for neurophilosophy. Searle (1983) refined the account with self-referential intentions: intentions-in-action have content specifying that the intention itself causes the movement. Bratman (1987) developed planning theory: actions execute intentions, understood as plan elements with functional roles that settle what to do and coordinate behaviour over time. Pacherie (2006, 2008) extended this planning approach into a dynamic hierarchical model distinguishing three levels of intention operating at different temporal scales. The DPM model (Distal-Proximal-Motor) specifies how intentions cascade from abstract plans to executed movements through integrated, coordinated activity across hierarchical levels (Mylopoulos & Pacherie, 2019).

Distal intentions (D-intentions) operate at the largest timescales, representing abstract reasoning about means and plans. They provide action plans that remain mostly descriptive and abstract, not directly tied to an immediate action context. A climber forms the distal intention "I want to summit El Capitan next summer" months before attempting the route. This intention involves conscious deliberation, abstract representations, and mental time travel, allowing the agent to simulate contingencies and consequences for future actions. Distal intentions establish what to do without specifying how or when.

Proximal intentions (P-intentions) anchor these abstract plans in concrete situations. Their function is temporal and situational anchoring: transforming "summit El Capitan eventually" into "climb this specific route now." Proximal intentions integrate conceptual information from distal intentions with perceptual information about the current environment to yield

situated representations of actions to be performed. The climber at the base identifies this particular crack system, these specific holds, this weather condition. The content of proximal intentions cannot be purely descriptive but must be indexical, including pointers to features of the immediate situation. They specify both what to do and approximately how to do it, given current constraints.

Motor intentions (M-intentions) guide the actual execution at millisecond-to-second timescales. They represent actions with as much detail as motor representations, specifying the movements to be performed. The climber's fingers adjust grip pressure, body weight shifts across footholds, and movements flow without conscious deliberation. Motor intentions operate at the level where cognition interfaces directly with motor control systems. Pacherie argues these are genuine intentions, not merely motor representations, because they contribute to the phenomenology of agency and action awareness even at rapid timescales.

The DPM model's key insight is that action control emerges from integrated activity across all three levels simultaneously. Distal intentions provide goals, proximal intentions anchor in the situation, and motor intentions execute movements, but these levels interact simultaneously. The climber planning next summer's ascent (D-intention) while practising today's sequence (P-intention) while adjusting current grip (M-intention) experiences unified agency across temporal scales. These causal approaches dominate cognitive science because they operationalise through hierarchical specification and measurable temporal dynamics, providing mechanisms linking abstract goals to concrete movements.

Although the causal theory now sets the terms of debate, this reflects disciplinary convention more than genuine philosophical agreement, as it faces an unsolved problem that has persisted for 60 years. Picture a driver who wants to avoid a pedestrian and believes that turning the wheel sharply will do so. The urgency of this thought makes them panic; their hands jerk uncontrollably, the car skids on gravel, and by sheer luck, it swerves just enough to miss the pedestrian. The driver's mental states did cause the movement, yet it feels wrong to describe this as an intentional act of skilful steering. The causal theory cannot give a widely accepted account of what distinguishes *normal*, intentional reason-causing action from these *deviant* cases in which the same reasons cause the same bodily movement, but only by accident or through the "wrong" pathway. Davidson acknowledged the problem in 1973. Despite decades of sophisticated attempts, no solution commands consensus. The causal theory cannot specify what "the right way" means.

Phenomenology offers fundamentally different accounts emphasising embodied directedness rather than mental causation. Merleau-Ponty (1945/2013) described motor intentionality as pre-reflective bodily orientation toward the world. Actions emerge from two powers: solicitation by situation and projection of situation, forming a dynamic unity through what he called the intentional arc linking perception to action. This is not a causal mechanism but a lived structure. Husserl (1913/2012) grounded action in kinaesthetic consciousness, the bodily "I can" through which practical possibilities are given. Gallagher (2005) developed this into enactivist accounts, in which action enacts the world rather than representing a pre-given structure. These phenomenological approaches reject the representationalist framework entirely. No internal models, no mental states causing movements, just direct bodily engagement.

Pragmatism inverted the causal picture by treating habit (not intentions) as fundamental. Dewey (1922) argued that habit is "special sensitiveness to stimuli, standing predilections, means will" operating before conscious deliberation. Three-level structure of action: impulse, habit, and intelligent inquiry when habits are blocked. Most action is habitual, socially constituted through practice, not generated by mental states. Actions are transactional patterns across the organism and the environment. James (1890/2007) treated beliefs as rules for action, meaning itself consisting of practical consequences. For pragmatists, intention does not cause action. Habit enables action; intention emerges when habits fail.

Ordinary language philosophy questioned whether actions should be defined at all. Wittgenstein (1953/2009) rejected essentialist definitions through his family resemblance argument. Actions exhibit overlapping similarities without a shared essence. Seeking definitions produces pseudo-problems, "bewitchment of intelligence by language." Ryle (1949) diagnosed the "ghost in machine" as a category mistake. Mental processes are not separate from intelligent acts but manifest in them. Actions are dispositions, not occurrent states. Multiple stages exist; context determines what counts as action.

Philosophy does not provide a unified definition any more than ecological psychology does. The traditions diverge on methodology (objective scientific analysis versus agential perspective versus therapeutic dissolution), ontology (actions as events versus processes versus dispositions versus habits), and causation (mental states cause movements versus formal causation versus teleological explanation versus non-causal intentional structures). The traditions agree that intentionality matters, reasons explain, and action differs from mere behaviour. They disagree on what intentionality is (mental states, embodied directedness, patterns, habits), what kind of explanation

reasons provide (efficient causation, formal causation, teleological, constitutive), and what distinguishes action from behaviour. Some accounts emphasise decisions and plans (Bratman, Pacherie). Some emphasise intentions and beliefs (Davidson, Searle). Some emphasise causality as essential (analytic tradition). Some reject causality entirely (phenomenology). Some treat action as a primitive concept, refusing definition (Wittgenstein, Ryle).

The persistent lack of consensus after a century of sophisticated philosophical work suggests either that the problem is genuinely very hard or that philosophers are asking malformed questions. Both remain live options. Depending on which philosophical tradition one adopts, actions may involve or not involve intentions, decisions, causality, or plans. The conceptual analysis that might clarify what ecological psychology left undefined produces equally fundamental disagreement.

1.4. Actions in Neuroscience

Neuroscience operationalises actions conflating movements with decisions under the exploration-exploitation framework (Daw et al., 2006; Dolan & Dayan, 2013; Sutton & Barto, 2018). Exploration means performing new actions. Exploitation means repeating past actions with the anticipation of similar results. This framework treats "actions" as unified constructs that vary along a single spectrum, yet empirical patterns reveal dissociation.

Motor execution automation produces robust, replicable patterns. Reaction times decrease across training (Berlot et al., 2020; Nissen & Bullemer, 1987). Movement variability reduces over months of practice in pianists (Lampe et al., 2015). Error rates drop systematically across training in finger sequence tasks, sports skills, and musical performance. These signatures appear consistently across paradigms and reliably within individual subjects (Doyon et al., 2009).

Decision-level automation shows species divergence and replication failures. Rodent studies demonstrate reliable devaluation insensitivity after 5–8 days of training (Adams, 1982; Yin et al., 2006). Lever pressing persists despite outcome devaluation, suggesting decision-making has shifted from flexible to habitual. Yet human studies show systematic failures. Tricomi et al. (2009) demonstrated devaluation insensitivity in 16 participants, but de Wit and colleagues (2018) documented five replication failures across 304 participants. The decision-level habitization that appears robustly in rodents remains elusive in humans despite matched training protocols.

This dissociation reveals that neuroscience measures movements directly (kinematics, reaction times, variability) and infers decisions indirectly (through choice patterns, devaluation tests, model fits). Whatever actions

are philosophically, researchers record neural activity during movement execution, track behavioural changes with learning, and characterise how organisms interact with environments (Cisek, 2007; Cisek & Kalaska, 2010; Scott, 2004). The conflation persists because both movements and decisions vary along exploration-exploitation dimensions, but the empirical evidence shows they vary independently on their own spectra and through different mechanisms.

1.5. Defining Actions as Movements on the XPLR-XPLT spectrum

Three fields attempted to define actions. Ecological psychology left actions primitive, characterised only through circular reference to affordances (Section 1.2). Philosophy across five traditions failed to converge after a century of debate (Section 1.3). Neuroscience conflated movements with decisions under the exploration-exploitation framework, producing dissociated patterns (Section 1.4). Yet convergence exists beneath the disagreement.

All three fields treat actions as minimally involving observable movements. Ecological psychologists describe affordances actualised through bodily engagement with environments. Even anti-representationalist phenomenologists like Merleau-Ponty (1945/2013) characterise motor intentionality through movements that organisms make. Pragmatists like Dewey (1922) ground action in habits, which are patterns of movement shaped by practice. Causal theorists like Davidson (1963) and Pacherie (2006) define actions through movements caused by mental states across timescales. Neuroscientists measure kinematics, reaction times, and execution patterns. The disagreement concerns what other actions require beyond movements (intentions, plans, decisions, mental causation, phenomenological directedness). The agreement holds that actions must at least include organisms moving through environments.

All three fields recognise organism-dependence. Ecological psychology emphasises affordances as organism-relative, grounded in capabilities and body configurations (Section 1.2). Philosophy documents this through Pacherie's DPM model, showing individual temporal scales, Dewey's person-specific habits, and Merleau-Ponty's embodied skills varying across organisms. Neuroscience demonstrates individual differences in the progression of movement automation (Lampe et al., 2015). Actions depend on what organisms bring to situations.

Since actions involve movements and are organism-dependent, I turn to experiments that measure movements. Kinematics, reaction times, variability, force production, and trajectory can be recorded with precision. Movements vary systematically across learning. A novice driver searches for road

edges and adjusts reactively. An expert driver tracks curve exits through precise eye movements lasting fractions of a second (Lappi et al., 2013). A pianist practising a new piece attends to each note placement. After months, the piece executes automatically while the pianist thinks about musical expression. The progression appears across finger sequences, sports skills, navigation, and tool use. This measurable variation provides the foundation for operationalisation. Therefore, I define actions as observable movements and their neural correlates. This is methodological pragmatism: by focusing on what all fields agree exists and can measure, I bracket the contested components (intentions, plans, decisions, mental causation) to establish a foundation.

The connection to affordances follows from organism-dependence. Since affordances are organism-dependent possibilities for action (Section 1.2), and organism-dependence operates through capability variation, which in turn instantiates as movement repertoires, then characterising how movement repertoires vary should reveal how affordances vary. A climbing wall presents different affordances to novices and expert because their movement capabilities differ systematically. The novice performs exploratory movements, carefully adjusting each handhold. The expert executes automated sequences, the same physical placements now performed fluidly. By characterising this movement variation along the exploration-exploitation (XPLR-XPLT) spectrum, I show how environmental features offer different affordances to organisms with varying movement repertoires.

Section 2 establishes the XPLR-XPLT spectrum through behavioural evidence and neural mechanisms. The framework contributes a mechanistic specification for the organism-dependence that both dispositional and relational camps accept. Training transforms how organisms move. This transformation changes what environments afford. The wall hasn't changed. The organism's movement implementation has. This is what neuroscience can measure.

2. Mechanisms of the XPLR-XPLT Spectrum of Movement

Movements vary systematically from untrained (XPLR) to automated (XPLT). A pianist practising a new piece attends to each note placement, monitoring finger position and timing. After weeks of practice, the same piece executes automatically while the pianist thinks about musical expression. Experiments document decreases in reaction times, reductions in movement variability, and fewer errors over training (Berlot et al., 2020; Nissen

& Bullemer, 1987). This progression appears across finger sequences, musical performance, sports skills, and navigation.

2.1. Movement Automation Across Training

Practice transforms how organisms move. For example, competitive swimmers increase in-water force and sprint speed through improved stroke index: more distance per stroke at roughly similar or only modestly changed stroke rates (Santos et al., 2024). In cross-sectional comparisons, top-tier age-group swimmers differ from lower tiers mainly by longer stroke length, higher propelling efficiency, and reduced speed fluctuations, not just stronger pushes against the water (Barbosa et al., 2019). Water is "swimmable" differently.

Many studies investigating music performance support the XPLR-XPLT spectrum of movements. Pianists who train for months reduce the variability of their keystroke timing while maintaining the same average speed (Jabusch et al., 2009; Lampe et al., 2015). Similar changes appear across other musical skills. When advanced piano students practise wide left-hand leaps under "variable practice" conditions, they learn to hit the target keys with lower timing variability and more consistent key-strike velocities, even at fast tempi, compared with students who simply repeat the same leap over and over (Bangert et al., 2014). At the other end of the ensemble, percussionists display reduced variability in simple tapping and in the reproduction of complex rhythms, and this superior temporal precision generalises even to rhythms that lack a clear musical beat, suggesting that training sharpens a domain-general timing controller rather than just piece-specific patterns (Cameron & Grahn, 2014). Further, microtiming work on expert drum-and-bass duos shows that repeated performances of the same groove have highly reproducible "fingerprint" patterns of tiny asynchronies around the beat: global tempo is highly stable, while minor, style-specific deviations are preserved in a controlled, stereotyped way (Kilchenmann & Senn, 2015). Across these musical contexts, training pushes motor systems toward automated, low-variance timing at the structural level, while allowing constrained, task-specific micro-variation to remain as an expressive resource. Voelcker-Rehage's review of motor-skill learning in older adults (2008) adds a complementary pattern: older adults often preserve online, within-session gains but show reduced *offline* consolidation, so apparent improvements partially evaporate between sessions.

Precision sports display the same logic. In dart throwing, expert players either significantly reduce release-timing error or adopt hand trajectories that make a broad window of release times "good enough" for hitting

the target, showing that skilled performance relies on flexible, outcome-stabilising kinematics rather than rigidly identical throws (Beers et al., 2013; Nasu et al., 2014). In golf, Barzyk and Gruber's (2024) systematic review of 52 randomized controlled trials on putting and other golf-specific skills shows that training methods typically associated with movement automatization (external focus of attention, increased contextual interference, and errorless learning) reliably enhance shot accuracy and retention in (mostly novice) players, indicating that practice structure can be tuned to push performance toward more stable, efficient control regimes.

This training-based progression finds parallels in cross-sectional expertise comparisons in ecological settings. Pezzulo and colleagues (2010) showed that a rock-climbing route for a novice consists of XPLR affordances, as they carefully adjust each handhold. In contrast, for an expert, it consists of XPLT, which they execute automatically. Calvo-Merino and colleagues (2005) found dance expertise modulated motor resonance when observing familiar movement sequences. Valyear and Frey (2015) demonstrated that tool affordances depend on learned functions, with distinct neural patterns for familiar versus unfamiliar tool uses. Learning movements changes how environmental features engage neural systems. This provides direct empirical support for the claim that movement affordances vary along the XPLR-XPLT spectrum.

The XPLR-XPLT movement spectrum manifests across studies. Initial movement repertoire predicts how far practice can push a system toward automated performance, and how stable that automation remains under dual-task demands or pressure (Lampe et al., 2015; Poldrack et al., 2005). Some organisms remain stuck in high-conscious-control regimes: they reinvest attention into execution, show low functional variability and are prone to "choking" despite extensive practice. Others rapidly acquire high functional variability and robust automaticity, freeing attentional resources for exploration elsewhere. The same environmental features, therefore, present different affordances not only across an organism's learning trajectory but also across organisms with varying capacities for spectrum traversal. Organism-dependence is a concrete variation in how far and how fast training shifts movements from XPLR toward XPLT.

2.2. The Spectrum of Neural Implementation

The movement automation spectrum maps onto distinct neural architectures. The initial training engages associative networks, while the execution of trained movements correlates with sensorimotor networks across the cortical and subcortical regions.

In the cortex, the frontoparietal network implements what Cisek (2007) calls 'affordance competition'. Multiple movement possibilities are specified in parallel, then compete for selection. Cisek and Kalaska (2005) recorded from the dorsal premotor cortex in monkeys performing reaching decisions. Two potential targets appeared, then a cue indicated which to reach toward. During the choice period, 43% of task-related, directionally-tuned neurons discharged for both potential reach targets simultaneously, creating bimodal population activity. After the cue specified the correct target, selected direction activity increased while rejected direction activity was suppressed. Neural activity reliably predicted choices 110–130ms after the cue. Environmental structure specifies multiple possible movements; that is, the environment provides multiple affordances. Context influences which movements get selected. This pattern extends to grasping and other movement systems (Baumann et al., 2009).

Training investigated in laboratory settings transforms cortical implementation. Berlot et al. (2020) tracked 26 participants across 5 weeks as they performed finger sequences with 7T fMRI, documenting decreases in movement time. Neural pattern reorganisation in dorsal premotor cortex and superior parietal lobule occurred during weeks 1–2, then stabilised during weeks 2–5 despite continued behavioural gains. Ariani and Diedrichsen (2019) demonstrated that reaction times for trained sequences decreased from approximately 600ms to 400ms across 4 days. Similar frontoparietal-to-sensorimotor shifts and reductions in overall activation are observed in other motor sequence paradigms as skills become more automatic, with early learning recruiting widespread prefrontal, parietal and medial temporal regions and later stages relying more on primary motor, premotor and thalamic circuits (Debas et al., 2010; Karim et al., 2017). The cortical reorganisation from associative to sensorimotor areas maps onto the XPLR-XPLT movement spectrum.

Musical training provides a convergent example of training-related neural reorganisation in a more ecological task. Olszewska and colleagues' review of longitudinal studies shows that even short piano interventions can alter activation within the dorsal auditory stream and increase functional connectivity between auditory and motor regions. At the same time, months-long training produces structural changes such as increased fractional anisotropy in the corticospinal tract and corpus callosum (Olszewska et al., 2021). A recent longitudinal fMRI study of novice keyboard learners scanned at 1, 6, 13, and 26 weeks of training found that playing increasingly complex pieces initially engaged associative brain areas, and that prolonged training was associated with decreased activity, while

performance improved (Olszewska et al., 2024). The authors interpret this as a shift from effortful, integrative control toward more efficient, automatized sensorimotor routines, constituting a music-specific instance of XPLR-XPLT traversal in neural terms.

Striatal mechanisms contribute to movement automation, though the picture varies across species. In rodents, instrumental conditioning studies (lever pressing, devaluation paradigms) demonstrate differentiation between the dorsomedial (DMS) and dorsolateral (DLS) striatum. Yin and colleagues (2005, 2006) showed that DMS lesions impair the formation of new associations, whereas DLS lesions impair the automation of movements. However, this functional segregation is not absolute: Stalnaker and colleagues (2010) found both regions encode both stimulus-response and response-outcome associations, indicating integration between associative and sensorimotor subcortical structures.

In humans, mapping the subcortical neural correlates of training-related changes in movement is more complicated, and the details of striatal involvement remain an open question (Basile et al., 2021). The homology claim rests on functional properties and connectivity, not pure anatomical correspondence (Balleine & O'Doherty, 2010). Human neuroimaging confirms striatal involvement in movement automation (Janacsek et al., 2020), but the relative contributions of caudate versus putamen regions, and whether they map cleanly to rodent DMS/DLS distinction, remain contested. Movement automation is clearly evident at the behavioural level across species; the neural implementation becomes increasingly complex as organism complexity increases.

3. Dispositional Properties and Relations Fit the Spectrum

In the first section, I introduced the dispositional-relational split discussing the ontological status of affordances. In the second section, I documented behavioural evidence and neural mechanisms implementing the XPLR-XPLT spectrum of movements through frontoparietal and striatal neural correlates. This section shows the compatibility of the XPLR-XPLT spectrum with the dispositional-relational debate. The experimental evidence constrains but does not determine the ontological status of affordances.

Recall Turvey's (1992) dispositional account from Section 1.1. Affordances are real environmental properties constituted by physical structure. They exist independently but actualise only when meeting complementary

organism capabilities. A staircase's climbability is "out there" as a dispositional property, actualised when a bipedal organism with appropriate leg length encounters it.

Stoffregen's (2003) relational stance challenged this. Affordances do not inhere in the environment or the organism but emerge from their relationship. They are properties of animal-environment systems, not of either component in isolation.

The dispositional view interprets behavioural changes as transformations in actualisation capacity. The climbing wall presents specific geometric features – holds at particular distances, angles, and surface textures. These physical properties constitute dispositional affordances that exist independently of any climber. When a novice encounters the wall, their motor affordances lie on the XPLR end of the movement spectrum. Training changes the movement repertoire and hence shifts affordances toward XPLT (sensorimotor implementation, automatized striatal execution). The wall hasn't changed its affordance structure. The organism's capacity to actualise those affordances has changed through behavioural training. This interpretation preserves environmental realism: affordances are "out there" as Turvey argued, while organism-dependence operates through varying actualisation capacity.

The relational view interprets the same neural changes as a transformation of the affordance itself. Affordances are relations between an organism's capabilities and environmental features (Chemero, 2003). The novice climber's behavioural repertoire constitutes one side of this relation. The environmental features (wall geometry, hold distances) constitute the other side. The affordance emerges from their relationship – it is neither in the organism nor in the wall. Training transforms the organism side of the relation. XPLR neural patterns shift to XPLT patterns (sensorimotor dominance, automatized execution). This transformation changes the relation itself. The novice-wall affordance (careful handhold selection) differs from the expert-wall affordance (fluid sequence execution). The wall's geometric features remain constant, but the affordance-as-relation transforms because one relatum changed.

The framework provides what both accounts lacked: a mechanistic specification. Dispositional accounts needed neural detail about how actualisation works; the spectrum shows that organism-dependence operates through action automation. Relational accounts needed empirical grounding for relation transformation; the spectrum shows systematic reorganisation along XPLR-XPLT trajectories. Both camps gain precision.

4. Can the XPLR-XPLT Spectrum be applied beyond the movements?

I deliberately focused on observable movements: kinematics, reaction times, and neural activity during execution. I ignored decisions, intentions, plans, and counterfactuals. Everything not directly observable in biomechanics and brain activity. By operationalising actions as observable movements and applying the XPLR-XPLT spectrum on movements, I analysed what everyone can agree on.

In this section, I examine how my methodological choice positions the framework within the direct-representational debate that discusses processing mechanisms. By operationalising actions as observable movements and characterising their XPLR-XPLT variation, I aligned with the direct perception: immediate sensorimotor coupling. This focus brackets the processes that representational accounts emphasise: planning, imagination, and counterfactual reasoning that operate beyond immediate movement execution. Section 4.1 documents the debate. Section 4.2 shows how temporal extension might apply the XPLR-XPLT spectrum to decisions at longer timescales where representational processes presumably engage.

4.1. Representational and Direct Camps seem Incompatible

The direct-representational debate runs deeply, dividing researchers and research programs. Gibson (1979/2014) rejected representational theories on epistemological and metaphysical grounds. Information in ambient energy arrays "is not conveyed. It is simply there" (p. 111). Chemero (2009) extended this anti-representationalism through radical embodied cognitive science, arguing cognition operates through agent-environment dynamics without computations over representations. Bruineberg, Kiverstein, and Rietveld (2018) developed the ecological-enactive synthesis at the University of Amsterdam, claiming organisms engage affordance landscapes through skilled intentionality without representational mediation.

Representationalist accounts developed in parallel. Hohwy (2013) argues predictive processing implements Helmholtzian unconscious inference through hierarchical generative models. Brains minimise prediction error by maintaining internal models standing in for external reality. Hohwy (2016, p. 1) explicitly rejects enactivism: "PEM [prediction error minimisation] should make us resist conceptions of [a mind-world] relation on which the mind is in some fundamental way open or porous to the world... Instead, PEM reveals the mind to be inferentially secluded from the world." Gładziejewski (2016) defends structural representationalism, arguing pre-

dictive coding structures play "genuinely representational" functions within cognition.

Integration attempts failed. Early work (2015–2018) asked: "Can we reconcile?" The University of Wollongong's Australian Research Council project explicitly funded compatibility analysis (2017–2022). Multiple special issues and collaborations attempted integration. Constant and colleagues (2021) proposed the most prominent bridge-building by suggesting that active inference accommodates both approaches through distinct computational pathways. Representational inference uses internal models for perception and planning, while deontic pathways implement direct sensory-action loops for habitual responses. Amsterdam researchers engaged constructively, suggesting active inference might solve "the war" (Bruineberg et al., 2018). Hohwy resisted, maintaining that even "frugal" strategies require rich internal models. Key figures acknowledged "parting ways" (Gallagher, 2023). Despite institutional support for reconciliation, philosophical commitments proved irreconcilable. The debate shifted from seeking a unified theory to explaining each approach's distinct explanatory domain.

This debate concerns cognitive status: does perception require internal models or operate through direct information pickup? The XPLR-XPLT spectrum of movements addresses a different question at the functional level: how do movements vary from flexible to automated, and which neural systems implement this variation? The neural mechanisms of movement automation constrain but do not determine positions on representational necessity. Showing that dorsomedial and dorsolateral striatum compete and cooperate in implementing flexible and automated movements doesn't resolve whether those movements require, constitute, or operate without internal models.

The XPLR-XPLT spectrum is neutral regarding representational necessity as the spectrum can be applied to movements, but also to decisions and intentions. Applied to movements, the spectrum characterises immediate sensorimotor coupling, the domain addressed by direct perception theories. Applied to decisions, planning, and mental simulation, the spectrum would characterise processes requiring representational distance, the domain that predictive processing and planning theories address. By focusing on movements (Section 2), I characterised what could be considered "the direct side".

Alternatively, movements could be interpreted as representational. Accepting Hohwy's (2016) claim that all neural processing involves representation, evidence from behavioural, neuroscientific, and philosophical re-

search indicates that not all representations are equivalent. The question becomes quantitative: which representations mediate which actions? Motor affordances require minimal distance: frontoparietal networks specify multiple movement possibilities (Cisek, 2007), striatal mechanisms contribute to action selection (Dolan & Dayan, 2013), and sensorimotor areas execute (Berlot et al., 2020). Even if everything is a representation, there seem to be qualitative differences between the representations themselves. The next subsection considers how the XPLR-XPLT spectrum might apply to the intentions and decisions.

4.2. Temporal Extension: From Motor to Distal Affordances

The XPLR-XPLT spectrum of movement characterises movements at immediate timescales (milliseconds to seconds). This addresses motor affordances, in which the organism directly couples to the environmental structure through sensorimotor loops. However, organisms also plan routes never taken, imagine movements before executing them, and consider counterfactual scenarios. These processes operate at extended timescales (seconds to minutes to hours) and require representational distance from immediate sensory input. How can the XPLR-XPLT spectrum be applied to decisions (representations) beyond movements (direct coupling)?

Neuroscience research on planning, imagination, and counterfactual reasoning suggests this extension is possible. These processes engage predicted outcomes (Rudebeck & Murray, 2014), mental simulation (Ma et al., 2025), and sequential control (Desrochers et al., 2015) operating beyond immediate execution. Just as movements vary from XPLR to XPLT, decisions about which movements to attempt could vary along the same spectrum: exploratory decisions sample new possibilities, exploitative decisions repeat past successes.

This neural mechanism correlates with Pacherie's DPM model from Section 1.4. Recall that distal intentions operate through abstract planning with mental time travel, proximal intentions anchor these plans in immediate situations through indexical content, and motor intentions guide millisecond-to-second execution. The DPM's key insight was to integrate activities across levels simultaneously, rather than through sequential handoffs. Affordances map onto this hierarchy.

The temporal hierarchy maps the movement-decision distinction onto representational distance. Motor affordances (Section 2's focus) operate where movements couple directly to environmental structure through frontoparietal and striatal implementation. Distal affordances operate where decisions require representational processes beyond immediate execution.

The XPLR-XPLT spectrum empirically characterises motor affordances. Whether it extends to proximal and distal levels defines the research program this framework enables.

Neuroscientific evidence indicates neural architecture spanning these timescales. Orbitofrontal cortex encodes cognitive maps for outcome prediction and inference (Ma et al., 2025; Wilson et al., 2014) (Wilson et al., 2014; Ma et al., 2025), providing teaching signals that update sensory representations based on expected outcomes (Wang et al., 2023). Critically, OFC projects directly to the striatum, influencing action selection through these predictions (Rudebeck & Murray, 2014). This connects distal affordances (OFC outcome predictions) to motor affordances via the striatal mechanisms documented in Section 2. Rostrolateral prefrontal cortex supports intermediate timescales through sequential control (Desrochers et al., 2015). The progression from OFC through rostrolateral and frontoparietal networks to sensorimotor execution aligns with the temporal hierarchy from the DPM model.

The temporal hierarchy reveals a deeper question. If the XPLR-XPLT spectrum applies neutrally across timescales of actions-affordances, then what explains the apparent incompatibility between direct and representational camps? Motor affordances correspond to sensorimotor processing, proximal affordances correspond to executing a plan, and distal affordances correspond to planning itself. These are spatiotemporally extended processes that engage "direct" and "representational" processes in varying degrees. Even if everything is representational, some representations are more "direct" than others. The XPLR-XPLT spectrum runs orthogonally and can be applied to movements, intentions, and decisions. As such, it can identify behavioural and neural correlates differentiating novelty from automation across these domains.

Conclusion

The XPLR-XPLT framework provides what affordance research lacked: a mechanistic specification of organism-dependence through measurable movement variation. By operationalising actions as observable movements ranging from exploratory to automated, I characterised how the same environmental features present different affordances to organisms with varying movement capabilities. A climbing wall affords careful handhold selection for novices and fluid sequence execution for experts. The variance in movement repertoire correlates with cortical and subcortical reorganisation of

the frontoparietal and striatal connectivity. Training changes neural implementation. This changes what environments afford.

By focusing on observable movements and their neural correlates, I characterised affordances at the timescale where perception is as direct as it gets. The temporal extension of planning, imagination, and counterfactual reasoning would characterise affordances at timescales at which representational processes engage more. Neural implementation of behavioural automaticity in humans suggests that movements and decisions are intertwined. If the XPLR-XPLT spectrum extends from motor to proximal to distal affordances through OFC prediction and rostrolateral sequential control, it would bridge timescales from milliseconds to hours, showing how the same organism deploys different mechanisms across temporal scales.

The XPLR-XPLT spectrum of movement measures behavioural patterns and seeks neural underpinnings that both camps can recognise. Extending it from movements to decisions defines future work. Affordances vary along the XPLR-XPLT spectrum because organisms' measurable movements do so as well. Behavioural neuroscience measures what philosophy debates.

NOTE

[1] I use movement and motor interchangeably.

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