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ORIGINAL RESEARCH

What is active touch?

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Abstract
What is active touch? A common conception of active touch gives a rough but rather intuitive sketch. That is, active touch can be understood as mainly object-oriented, controlled movement. While parts or the totality of this characterization is espoused by an important number of researchers on touch, I will argue that this conception faces important challenges when we pay close attention to each of its features. I hold that active touch should be considered as before all else purposive. This view has its roots in the active sensing literature in robotics but will be amended to give insight into human touch in the natural world.

Keywords Active touch · Passive touch · Haptic sensing · Touching · Touched · Active sensing · Purpose · Goals

1 Introduction

What is active touch? According to what I will call the Common Conception, active touch tends to involve movement, object-orientation, and controlled while passive touch is mostly subject-oriented, static and uncontrolled. We have good reasons to adopt this Common Conception: it is at the very least a tacit assumption of successful research on touch and it appeals to useful intuitions about what is specific about this sense. Yet probing more deeply into the details of the Common Conception opens a series of pressing questions. Here are a few. If active touch involves movement, what type of movement makes touch active? Accepting that active touch involves some form of control, over what is there control? Do researchers who appeal to the object/subject orientation of touch mean the same thing by this distinction?

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In this paper I will defend a purpose-first view on active touch in order to tackle these questions. What purpose offers is a step toward understanding why some of the cluster properties featured in the Common Conception hold in some cases and not others. Starting from purpose in our understanding of active touch is not a call for an upheaval in empirical and theoretical thinking on active touch but offers to cast a new light on experiments of past and motivates new hypotheses for those of future. To demonstrate this, I will largely focus on a tool touch localisation experiment conducted by Luke Miller et al. (2018).

My purpose-first view on active touch will be much indebted to the neurorobotics literature on active sensing even though the status of purpose in this literature will need to be circumscribed.[1] So far, the teachings have mostly been unidirectional with the neurorobotics literature drawing upon human and nonhuman animals to design robots that are better suited to tackle real-world interactions. I propose, conversely, that this literature can also shed light on human active sensing. A first line of inspiration stems from a particular methodology inherited from cognitive science and neurorobotics with regard to what it means to understand a cognitive or perceptual process: it is to be able to reverse-engineer it. While much of the neurorobotics literature echoes parts of the Common Conception, a group of researchers working on active sensing and perception in this field (Aloimonos, 1990; Bajcsy, 1988; Bajcsy et al., 2018; Tsikos & Bajcsy, 1991) understood that one has to start from purposiveness to build an active sensing system. It is in this sense that my view frames active touch starting from purpose. A second particularity of my proposal, which follows from the first, is that the purpose-first view requires us to give up on some intuitions about active touch reflecting a *sui generis* feature of touch. Indeed, while my focus here will be on active touch, the conclusions drawn from this analysis should be applicable to active perception in other sensory modalities as well.

Finally, I will add three refinements to the neurorobotics' understanding of active sensing to clarify active touch in natural settings for humans. That is, (1) conscious purposiveness does not exhaustively capture active touch, (2) the mark of goal-directedness is outcome tracking, and (3) singular goals in behaviour is often but a (useful) abstraction.

2 The common conception

What I will call the Common Conception of active touch seems relatively intuitive and unites philosophers and scientists of various creeds. The Common Conception can be summarized as such:

[1] I use purpose-first here not exactly in the same sense as epistemologists might refer to knowledge-first epistemology following Timothy Williamson. I do not make commitments as to a metaphysical priority of purpose (or whether it is or isn't a constituent of something else). However, there is a pragmatic priority of purpose, on my view, in active touch in line with my attempt to make productive use of the insights from robotics. I thank one of the reviewers for pushing me to clarify what I mean by purpose-first.

> **Common Conception**: whereas active touch is *mostly* controlled, object-oriented and involves bodily movement, passive touch is *mostly* uncontrolled, body-oriented and without movement.

Although scientists and philosophers of touch starting from this intuition lay emphasis on parts of the common conception, holding all three is relatively uncontroversial. Chapman's (2009) entry on "Active Touch" in an encyclopaedia of neuroscience defines active touch as "the act of touching, and implies voluntary, self-generated movements." This is philosopher Matthew Fulkerson's (2014) characterization of passive touch: "Passive touch *tends to be* […] bodily directed, to involve no control, and to occur on parts of the body over which we have little exploratory capacity" (p. 7, emph. mine). As we will see in detail in Sects. 3.1–3.3, many philosophers and scientists try to clarify the relation between the features of this conception while starting from movement, object-orientation,[2] or control.

An important feature of the Common Conception, which also explains why it is so uncontroversial is that it isn't a *stricto* sensu definition insofar as it does not aim to narrow toward necessary or sufficient conditions of active and passive touch but their regular correlative features. The absence of a definition for active touch may not be necessarily worrisome for research. After all, cognitive scientists are able to make important progress without an operative, agreed-upon definition of cognition since scientists aggregate more often around fruitful research questions rather than well-defined terms (Allen, 2017). For Cecilia Heyes, the difficulty in circumscribing cognition should not worry us because: "the concept of cognition isn't doing, and doesn't need to do, much scientific work. It's just a generic term for a bunch of phenomena that are more precisely defined—like learning, memory, perception, attention, categorisation and motor control." (in Bayne et al., 2019). In a similar sense, at the interface of research on perception and action we can claim from the vantage point of the Common Conception that *the concept of active touch doesn't need to do much scientific work*. Rather, it is the more precisely defined phenomena it circumscribes (viz. movement, control, object-oriented touch) that act as scientifically useful generics that can always be further broken down into their even more precisely defined processes.

3 Three features of the common conception

As we will see, one reason to take up the Common Conception, besides the general consensus around it, is that it is fairly useful for capturing intuitive examples of active touch. In what follows, I will motivate each of these earmarks of active touch and highlight some of the problems encountered in focusing too strictly on any single feature of the Common Conception of active touch. Although this paper may appear overly negative, dismantling what I consider some inexact characterizations of active touch, I will argue in a second, constructive step that we should understand active

[2] I will use object-oriented touch, touching, and *touchant* to all mean the same thing.

touch before all else as purposive. The notion of purpose will provide a red thread for understanding why the Common Conception has been successfully assumed in touch research, that is why active touch is mostly accompanied by a movement, object-oriented and controlled. If my position is correct, then we will gain a better understanding of the tool-mediated touch experiments conducted by Miller et al. (2018) and liminal cases of active touch.

3.1 Active touch as movement paired with touch

Active touch is most readily understood as tactile perception coupled with movement or, by the lights of more radical theorists, as *moving touch* or haptics.[3] Besides the obvious semantic proximity between "motion" and "activity," a reason to adopt this view can come from a cursory glance at the active sensing literature in robotics which uncovers a fundamental link between perception and movement. The computer scientist John Aloimonos et al. (1988) were among the first to point out the role of motion in easing the cognitive load of visual perception. That is, when conceiving algorithms involved in deducing object shape from contour or recognizing object motion, the field of computer vision was much advanced from taking stock of the active role of the perceptual system and its mediating action *vis-à-vis* its environment. While complex algorithms could provide interesting answers for difficult perceptual tasks, anthropomorphising non-human perceptual systems to take into account behaviour and environment led to simple but quickly processed algorithms that provide timely solutions in line with human perceptual systems (Ballard, 1991). Accordingly, given that exploratory movements are ubiquitously present in human and nonhuman animals, a biomechanical analysis of a sensory apparatus offers constructive, implementation-level constraints on sensor responses and gives insights as to how motor commands drive sensory information about the environment.

This is particularly the case for touch where, despite the progress made in the past decades, tactile sensing in animals offers solutions to complex perceptual problems that are yet to be fully integrated in robotic sensing. To take only one of the mammalian paradigms that has been picked up in robotics, the study of the rat's vibrissal system and whisking behaviour reveals that sampling a given object from various angles allows it to extract the shape of the 3D object (Hartmann, 2009; Solomon & Hartmann, 2008). This exploratory movement proves necessary to counteract a constitutive implementation constraint: lateral slip, or the whisker sliding out of its plane of rotation, makes shape inference difficult without movement. Some of the functional specificities of whisking in mammals can then be introduced in biomimetic whiskered robots as a stark improvement on passive binary collision-detectors, the analogue for tactile sensing found in many robots (Pearson et al. 2007; Prescott et al., 2009, 2020). In short, as some of the leading robotics researchers in the field of active touch sensing frame it in their introduction to an IEEE special section on

[3] Among the vast number of theorists and scientists who adopt the view, here is just one example: "I shall suggest that it is solely *the integration of touch with movement—giving rise to active touch*, or "haptic" perception—that furnishes us, within the "tactile" domain, with perceptual consciousness at all…" (Smith, 2002, 149, emphasis mine). The more radical view can be found Noë (2004, 96ff.) who views touch as "intrinsically active" since, following Berkeley, it "is in effect a kind of movement.".

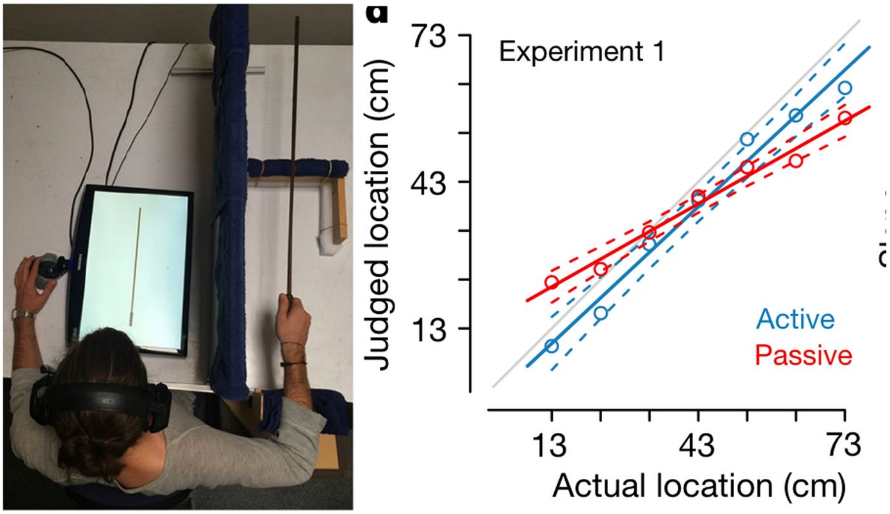

Fig. 1 Experimental setup in Miller et al. (2018) experiments and the difference between active and passive conditions

Active Touch Sensing, active touch captures one of the distinctive hallmarks of the haptic modality, viz. the “close interplay between movement and somatosensation” (Visell et al., 2016). I will return to this literature to flesh out this bare-boned characterisation of the active sensing robotics literature.

This understanding of active touch as moving touch is a fundamental assumption at the basis of the previously mentioned experiment by Luke Miller and colleagues. In their paper “Sensing with tools extends somatosensory processing beyond the body” (2018) the researchers present self-generated movement (active sensing) and passive reception of impact (passive sensing) as two distinct localization tasks with only the former mobilizing motor-related signals in addition to sensory signals.[4] This distinction is grounded in the marked difference in performance accuracy across a series of tasks: participants could either wield the tool and come into contact against the object or the experimenter moved the object into contact with the tool (see Fig. 1 for an illustration of the setup). By moving a cursor onto a graphical representation of the tool and clicking on the appropriate point of contact, the participants were to make a judgment on the point of contact of a wooden block with the unseen rod. While in both cases the participants performed above chance (slope = 0.25), active sensing—understood as the participant moving her hand toward the point of contact—was highly accurate (0.93 ± 0.09). By contrast, under the passive condition where the contact was elicited by the research, the participant was considerably less accurate at localizing the point of contact (0.57 ± 0.04). The series of experiments designed by Miller and colleagues produce multiple lines of evidence for the exten-

[4] To be clear, Luke Miller and his colleagues do not aim to make a claim about active or passive touch per se but active and passive conditions within their experimental setting.

sion of somatosensory processing beyond the body.[5] Three measures allow us to evaluate the researchers' claim: (1) accuracy in localizing contact, (2) that the contact-related somatosensory information is tool-centred, and (3) the nervous system's ability to anticipate and decode the structural dynamics of the rod. Only the first and third measures will be explicitly discussed here.

Going back to the phrasing adapted from Heyes, we can claim yet again that active touch itself was not the operative, scientifically useful concept here, but mobility and immobility were. The two tasks further characterise active touch in relation to the accuracy of localisation with active touch better suited for judgments on the actual location of impact on the rod. Nevertheless, although this characterisation of active touch allows the researchers to draw the conclusion that localisation judgments are better in one condition rather than the other, it leaves open an interesting research question that the researchers themselves acknowledge (cf. Alsmith, 2023). That is, why were participants still *quite* successful at localising touch, even in the passive condition? I will come back to this question in §3 but suffice at this moment to say that an answer can be given by interpreting both conditions as cases of active touch while acknowledging the role that movement makes in increasing accuracy of sensing.

At this juncture we must ask a further question that should ultimately clarify some of the insights we have gained so far. While this connection between touch and movement opens the way for haptic research, what *type* of movement might interest the researcher? This question will require further attention further down the line but, to anticipate, it does seem right to discard some counterintuitive amalgamations. Although it seems trivially true that using my hand to test the strength and feel the surface of a crevice while climbing is a form of active touch, it would seem overly permissive to call the soreness of my feet while walking an example of active touch. Intuition is a double-edged sword especially in the field of haptic research and my purpose here is not to stop at these intuitions but give a plausible explanation as to why some of the stronger ones stand. Part of Gibson's motivation in writing a paper on active touch (1962), which will be central to the following section's focus on active touch as object-oriented touch, was to dispel what he calls the kinaesthetic view. This kinaesthetic view can be simply formulated as the idea that active touch is touch coupled with movement.

3.2 Active touch as object-oriented touch

It is one of the idiosyncratic properties of our tactual sensing that it can be either self- or object-oriented: e.g., while I use touch to inspect the smoothness of a polished finish, I do not attribute this smoothness to my fingers. This is an insight that one can find in Gibson's "Observations on Active Touch" (1962), even though this dual aspect of touch has a long and rich philosophical history that precedes the ecological psychologist.[6] His rich text opens up with the following definition: "Active

[5] Their work culminated in the recent insight that our nervous system repurposes bodily tactile localization inference on the tool (Miller et al., 2023, 2022).

[6] Although, as Kearney (2020) points out, the touching-touched distinction was already present in Aristotle, we can credit the phenomenological tradition for having made the most extensive use of it, see for

touch refers to what is ordinarily called touching. This ought to be distinguished from passive touch, or being touched." For him, the distinction here concords with that between endogenous and exogenous agency or, in an Aristotelian sense, between activity understood as exploration and passivity understood as reception. This endogenous sensing is also often related to or conflated with the voluntariness or spontaneity of touching.[7] To understand why active touch framed as endogenous exploration is different from the previous characterisation, it is worth following Gibson's reasoning a little longer. As we saw in the previous section, for Gibson, psychologists had made an error in taking active touch to be a blend of kinesthesis and touch proper. One failure of this view is that it overlooks the purposive character of touching. I will return to the purposiveness of active touch in §3 and §4. The second objection to the kinaesthetic view is that what we mean by it is rather ill-defined and kinesthesis is not a unified sense. Without undermining the role of movement in perception, it remains nevertheless important to specify what type of movement is tied to active touch. The advantage of adopting this Gibsonian definition is that it helps carve out a nuance that the previous view did not allow. Indeed, there seems to be a crucial difference between reflex movements or other-initiated movements and voluntary, self-generated movements.

The Gibsonian definition sketched here is aligned with the way some haptic sensing researchers understand the distinction between active and passive tasks. In the active task, the participants form an intention to produce a specific movement and in the passive one the experimenters induce the movement from the 'outside' as it were or by moving the surface on which contact is made (e.g., Kalckert & Ehrsson, 2014; Simões-Franklin et al., 2010; Zhou et al., 2023). This was arguably also the case in the Miller et al. experiment insofar as, in the passive condition, the experimenters induced contact whereas in the active condition, contact was initiated by the participant. Furthermore, returning to the refrain that active touch is not scientifically fruitful but its features are: active touch understood as *touching* yields specific experimental insights about unity of touched object, mobility and intensity for Gibson (1962, 482). In fact, Visell et al.'s (2016) characterisation of active touch, referenced in the previous section, also directly aims to include this Gibsonian insight when they claim that active touch sensing involves "touching" rather than "being touched."

On this view, active touch is exploratory *touching* and endogenous while passive touch is receptive *being touched* and exogenous. But is this picture quite right? This would be true if researchers failed to dissociate their intuitive understanding of active touch from exploratory touch. A recent empirical contribution on active and passive touch builds on evidence that "different brain mechanisms are engaged during active and passive *exploratory* touch" (Zhou et al., 2023, emph. mine). What they call active and passive touch closely follows the difference between endogenous and exogenous movement outlined here. On the passive touch task, a subject of their experiment would hold her finger still as the interface moved beneath it and on the active touch task, she moved her finger away and toward her body on the interface that remained

example Merleau-Ponty (1945, 122) and Husserl (1989, 152ff.).

[7] Recall Chapman's (2009) definition of active touch as implying "voluntary, self-generated movements." As one reviewer helpfully reminded me, on some folk intuitions, active touch is spontaneous touch.

static. Their results show that there was less sensory attenuation in the passive condition. Their understanding of the passive and active touch distinction does not align with the one I defend here but the more interesting point is to consider why they took both active and passive touch as exploratory. They (rightfully) considered that at least in some cases *being touched* could be meaningfully exploratory. It is worth pointing out here that this is also why on my reading of the distinction, both Miller et al.'s passive and active conditions were exploratory.

Another way to read the distinction between touching and being touched draws less on whether the contact was self-initiated than the focal directedness of the tactile experience. In contemporary research, Frédérique de Vignemont (2018, 51ff; 2023) makes use of this distinction to ground her account of bodily ownership.[8] In the context of distinguishing the perception of our own and others' experience of touch, she explicitly aligns active and passive touch with touching and being touched: "it is important to distinguish between the active and the passive dimensions of touch, between *touchant* and *touché*." (de Vignemont, 2018, 130) Notice that this understanding of touch does not require (although it is often accompanied by) bodily movement. I can easily, for example, attend to my upper leg pressing against the lower while sitting still with my legs crossed and just as easily switch focus to the lower one feeling the weight of the upper one. What is less clear, however, is the contexts in which the "objective" or "subjective" sense might be more salient. In the classical example of touching my right hand with my left hand, it seems like I can easily switch from the experience of touching to being touched, but as notes Hartmann (2009, 686–87), it is notably difficult to shift focus to the scratching fingers while you scratch yourself.

This useful distinction is somewhat less clear in cases of distal touch, where the object or event felt through touch is not in immediate contact with the body (Alsmith, 2023). It is not so clear whether a stimulus localization task, whether on a tool (Miller et al., 2018) or on the body (Miller et al., 2022) is an example of being touched or touching. The oft-used example of the experienced driver *feeling* the condition of the roads makes plain the trouble: while one can have a subject-oriented experience of our hands, where does one feel the object-oriented dimension of this experience? On the wheel or on the tire?[9] To answer this question requires to favour one out of (what I suspect are) quite varying intuitions by stipulation.

Even in cases of proximal touch, where the difference between touching and being touched seems more salient, the phenomenology of dynamic interactions with our environment is oftentimes impure. As I push back against my work desk, I am never quite certain whether I experience the contact as *either* touching or being touched but a mix of both. Is the participant in Zhou and colleagues' passive condition touching or being touched by holding his finger still as the sample table moved under it? We

[8] In the bodily ownership literature a strong tradition dubbed the "Template" model (Martin, 1995, 272; O'Shaughnessy, 1989) views the tactual perception of external objects as dependent on bodily self-experience. See however Mizrahi (2023) for an important challenge to this model. Whether this subjective pole is another object or a *sui generis* form of awareness is an important but ultimately unrelated concern (Mattens, 2017).

[9] Although the former seems like a more probative description, it is worth noting here that the expert racing car driver is told to "focusing on sensing the tires' traction" (Lappi, 2018).

can extend this line of analysis to the Gibsonian reading that divides touch between endogenous and exogenous by claiming that, beyond constrained laboratory cases, what counts as self- or other-generated movement is often a question of degrees. To be sure, the point is not here to dismiss the usefulness of this distinction in formulating and testing useful scientific hypotheses but to argue that beyond some of the paradigmatic cases, the distinctions between touching and being touched or endogenous and exogenous movement is not so clear cut. Psychologist Bernhard Hommel has notably argued that dual-models of action control fail to provide criteria that could distinguish consistently exogenous and endogenous movements (Hommel, 2022; Hommel & Wiers, 2017).[10] The porosity of the distinction seems to be bidirectional: self-generated actions are often endowed with some automaticity and, conversely, other-generated actions are not always modulation or goal-free (Bargh, 1989; Bargh & Chartrand, 1999).[11] To be sure, Gibson's addition is an important step toward a better understanding of active touch, and I will come back to the important kernels of truth in his analysis.

3.3 Active touch as controlled touch

Moving away from the Gibsonian touching-touched distinction, Susan Lederman, one of the prominent researchers of human touch of the second half of the twentieth century, defined her own understanding of active and passive touch in the following terms:

> In our view, "active" and "passive" touch do not constitute a dichotomy, as suggested by Gibson (1962). Rather, the touching process may be considered more or less "active," depending upon the degree of control that the [subject] has over the various components of the touching process.
>
> (Lederman & Taylor, 1972)

Worth noting in Lederman and Taylor's characterization of active touch is the rejection of the binary view in favour of a spectrum of activity. It seems, at least here, that there is no such thing as a purely passive touch experience on Lederman's view. Although in later work she does contrast activity to passive tasks (e.g., Lederman, 1981), her important work with Roberta Klatzky consisted in evincing the limited range of "exploratory procedures," i.e. well-defined sets of movements used to pick out tactual features of objects, guiding touch (Lederman & Klatzky, 1987). These signature exploratory procedures include, amongst others, a lifting motion that is well-suited for detecting weight or a tangential motion against a surface for detecting texture. The second obvious feature of their view, which was already implicitly present in the Gibsonian reading of active touch, places emphasis on the last missing

[10] There is even some evidence to back the assertion that endogenous and exogenous action plans are similarly encoded (Richardson et al., 2020).

[11] Taking a gradualist stance also allows an easy explanation of mastery: as the violin player progresses in her art, her intended movements require less and less control (Wu, 2023, 48).

ingredient shaping our Common Conception: active touch is also often about *controlled* movement. What characterizes "control" in this context is the extent to which the exploratory movements used to interact with objects is endogenous. It is difficult, for the most part, to tease apart "control" and mobility on this view since, as Lederman makes clear, we are always dealing with degrees of activity. This insight again finds echoes in the robotics' active sensing literature if we consider that Bajcsy's seminal "Active Perception" (1988) paper defines active perception in vision and touch as an application of "intelligent control theory." (We will see more clearly in the next section what Bajcsy means by *intelligent* control theory). With this we get closest to a satisfactory understanding of active touch so far. This understanding of active touch as controlled movement is also what motivates Adrian Alsmith (2023) in his appeal to the experiment of Miller and colleagues as a case of distal touch beyond one's "control."

From this view, the relationship between control and bodily movement seems self-evident. And yet, the Common Conception starts taking shape once we try to understand how this picture relates to our previous distinction between the subject- and object-orientations of touch. Two important monographs on touch (Fulkerson, 2014, 9; Jones & Lederman, 2006, 61), have pointed out that in the absence of exploratory movements, we tend to experience tactile stimulation as changes on the body and not on the object with which we come into contact. However, as Fulkerson also points out, there are specific situations, where touch can be active and object-directed precisely because we are not moving. This is his example of a bug crawling on your skin while you're sitting still (2014, 7).[12] There is an active awareness of the insect's sharp legs even in the absence of control, insists Fulkerson. I will later maintain that the crawling bug example is only sometimes 'active touch' on my understanding of the active–passive dichotomy.

Adding control to our understanding of the Common Conception has the added benefit of further spelling out an early intuition. That is, if we accept the importance of bodily movement in active touch, what type of movement counts as active touch? The answer to this question seems to be, at this juncture, that controlled, self-generated exploratory movement is the desideratum for selecting the right movement in play in active touch. Even with this specification, we are still faced with an important question: if for the first feature of the Common Conception we identified *which* movement is important for active touch, here we ask ourselves *upon what* exactly active touch requires control. The reason why this first question should be asked at all is that what we might mean by controlled movement might not be as trivial as we might think at first glance. If control is a fine-grained and subpersonal property of the nervous system as it coordinates a pattern of muscle activation to achieve a movement from A to B, at least two computational problems arise. First, a selection (or degrees of freedom) problem in choosing the specific pattern of movements between a potentially infinite number of ways to reach an end-point in three-dimensional space (Bernstein, 1967; Seminara et al., 2019; Wu, 2011). To this Mitra

[12] Although here Fulkerson characterizes this example as a form of "active awareness" he later suggests that this is an example of passive touch (cf. Fulkerson, 2014, 68). This need not be a contradiction within the Common Conception.

Hartmann (2009) adds two further computational problems with only one being of interest for my purposes.[13] As she suggests, a finer-grained distinction of controlled movements involves feedforward and feedback control. Feedforward control is the specification of movement before it even begins. However, given that coordinated movements require flexibility and that the target of the exploratory movement can itself be moving, there also needs to be feedback control. The exact balance between the two thus requires specifying the situation under which active touch takes place, e.g. if the target is moving fast, active touch will mostly rely on feedback control.

To be clear, the purpose here is not to rule out the importance of kinaesthesis and controlled movement in touch but, on the contrary, to better situate the role of control and action without overstating our case. In the end, the Common Conception taken to the letter is caught between two dim prospects: either active touch is fully exhausted by motion, control, and object directedness and it is unclear what it adds to our understanding of tactile sensing or, active touch is not circumscribed by those features and the common conception is insufficient. My task will be to provide a more fitting definition for active touch that eschews this dilemma.

4 Active touch as purposive

The general picture that should emerge from the previous section is that most researchers understand active touch, in accord with the Common Conception, as a situation in which a perceiver performs controlled movements to better perceive the features of an object. Unsurprisingly, while these movements occur our attention seems to be riveted toward the object and its features. While the Common Conception presented a sensible way of capturing both our intuitions and scientific practice, focusing too narrowly on each property of the cluster presented important challenges for our understanding of active touch. Primarily drawing upon research in active sensing in robotics and neuroscience, this section will aim to refine our understanding of active touch. In this sense, the goal of this section will be twofold: (1) I will seek to go beyond the Common Conception and (2) I will attempt to make sense of why the Common Conception seems to intuitively hold.

Prescott et al. (2011), in their introduction to a thematic issue on active touch sensing, rehabilitate a Gibsonian definition of active touch by taking stock of some of the previously stated criticism. Indeed, instead of restricting active touch to cases where bodily movement is involved, they qualify active touch foremost as *purposive* and *information-seeking*. Thus, beyond the body's mobility or immobility, active touch should be better defined as intent over touch sensors toward achieving a specific goal. While this often does imply kinaesthetic transactions with the surroundings, the role of movement in touch can be better understood in light of this characterization of active touch. Their definition is Gibsonian since, as we saw in Sect. 3.2, one of

[13] The last computational problem concerns the trade-off between the ease with which one can plan movements in external coordinates and the difficulties of executing them in external coordinates. There then needs to be a transformation of the external coordinates to coordinate joint and muscle activity.

the latter's objection to the kinaesthetic view was that it fails "to take account of the purposive character of touching" (Gibson, 1962, 478; 2015, 175–76).

With this definition of active touch in mind, we can look back at the results of the active and passive conditions of Miller and colleagues' experiment with a different outlook. While my earlier characterization laid emphasis on the difference between the active and passive tasks, we can look at the glass as half-full: it is impressive that, although the participants remained motionless, they could localize contact with such accuracy. This way of looking at the experimental design and results is motivated by taking as central the purposiveness of active touch. Indeed, that the participants in Miller and colleagues' experiments were asked to make a judgment about the impact location on a rod by the experimenters *is* a sufficient condition for active touch, whether or not the participant's hand self-generates movement by tapping on the object. Even though the participants do not receive feedback about their performance or the correct impact location, the experiment's demand characteristics make their sensing purposive and information-seeking, i.e., the goal is to locate, and thus to make a judgment about the point of contact. Simply put, what they describe as a passive task *is itself a form of active touch*. Compare, by contrast, with a case where (distal) touch is truly passive: as you hold on to the handrail while going up a narrow staircase, you 'feel' your friend precariously grabbing onto the handrail a few steps down as she attempts to avoid a fall. Going back to the Miller et al. setup, what would make sensing on the rod an example of passive touch sensing would require the experimenters to ask the participant to locate touch on the rod *after* contact has been made. If, as I will argue, active touch allows for added precision in tactile sensing, in this passive touch condition there would be less accuracy than in the active touch tasks.

On the empirical front, it is important to insist that my purpose-first reading of active touch does not ask of scientists to give up on the Common Conception wholesale. In fact, as I will highlight in what follows, the purpose-first reading of active touch allows for an initial but partial answer as to why touch is indeed mostly object-oriented, controlled and coupled with movement. It seems sensible to think, as we saw in the case of cognition, that scientists are not waiting for definitions to produce their empirical findings. Yet the function of (re)definitions is, at least in this context, to produce an alternative view on previous findings and derive hypotheses for future research. This can then be made fully compatible with making distinctions between mobile and static tasks where even in cases of uncontrolled exogenous sensing, the touch can be deemed as goal-oriented and information seeking (Miller et al., 2018; Zhou et al., 2023).

With this in mind, we can think about the features of the Common Conception and understand how they gain their explanatory force. If active touch, as I argue here, should be understood as before all else purposive, we can start making sense of the tight link between sensing and movement, the experience of control as well as the phenomenal experience of object-orientation in active touch. Goal-oriented sensing behaviour explains which motions are relevant for better sensing and if any motion is required at all. After all, it comes as no surprise that the participants in the active condition of Miller et al.'s experiment were able to locate touch with much greater accuracy when goal-directed movement is allowed. While controlled movement brought us close to satisfactorily answering the *what?* motion question, control as well makes sense in relation to the goal. Miller et al.'s passive condition provides an example of a case where movement is not necessary for active touch but we can easily think of others. If my attention is rivetted toward the crawling bug in the earlier (Sect. 3.3.) Fulkerson example, I track its movements and certainly care about where it is headed. The passive touch contrast can be felt in a variant on the crawling bug: Camping Trip. Imagine you are on a lengthy camping trip, in the beginning you are particularly sensitive to the bug life around you, but as the trip goes on, you are less and less mindful of the innocuous bugs around you and on your skin to the point where you are only partially aware of their presence on your leg.

An objection to the purpose-first characterisation of active touch is that this revision gives up on an idiosyncratic feature of touch. It seems then that what was an intuitive property of touch alone, i.e. that one can use exploratory movements to get a better grasp of the features of an object, now becomes a distinction that can be applied to other senses as well. This could certainly be the case for at least vision and hearing. I take it that there is no *prima facie* difference in this regard between touch, hearing, and vision, for example. On this revisionary reading, the difference between active and passive touch becomes comparable to *hearing* and *listening* or *seeing* and *looking for*.[14] And I take this to be true, attentive, goal-oriented listening is purposive in a way that hearing simply isn't. This outcome should have been predicted given that the literature my view draws most of its inspiration from is an active sensing literature that has only more recently turned its attention from vision to touch. My modality-independent reading of the passivity-activity distinction makes use of a pervasive feature of perceptual experience: attentional capture. Imagine two scenarios that I will take to be analogous in their passage from passivity to activity. As you are talking with a person at a gathering, another person taps on your shoulder to say hello. This is a case of passive touch, as you had no goal and one of the distinguishing characteristics of this experience is an element of surprise. If this person maintains contact a little too long, you start tracking their hand with acute awareness. Compare this with Wu's (2023, 76–77, 116; Cherry, 1953) "cocktail party effect": as you are in deep conversation at a party, you hear your name being uttered in another part of the room. While you were vaguely hearing the conversation as background noise, once you heard your name you are now *listening in*.

A second objection to my purpose-first reading that follows the previous remark is that it is undistinguishable from an attended/unattended dichotomy of touch or sensing. A running theme in this paper has been the permeability of the dichotomies in research on touch and my descriptions of paradigmatic cases of active touch drew on the phenomenology of attention. Before defending the stance that we should avoid a hasty conflation between active and attended touch, I want to underline some of the important similarities between the two. For clarity's sake, I will limit my discussion mostly to the account of attention that is closest in proximity to my account of active

[14] Although I use the term active and activity instead of action to avoid the Sect. 2.1 conflation of action and movement this reading is compatible with Wu's (2023, 82) verdict on the relationship between action and attention. Thank you to one of the reviewers for pushing me on the distinctiveness of active touch.

touch as developed by Wayne Wu (2023, 2024; 2014).[15] Against some contemporary scientific voices who are sceptical about the unity of (visual) attention, Wu has made the case that we can go back to James's original definition of attention to accommodate both folk intuitions and empirical findings on attention. According to him, attention is the subject's mental selection of a target to guide behaviour (Wu, 2024). This functional definition also implies the inhibition of events and objects irrelevant to the target.[16] The starting point for his definition is the Selection Problem that challenged our understanding of active touch as controlled touch. For Wu (2023) then, attention is the solution to the selection problem. Notice that whereas attention offers a solution to the selection problem for him, purpose is the reason why there is a selection problem at all. If there were no targets for action or perception, there would be no selection problem that would require solving. Even if we were to take on his unified definition of attention, and there would be good reasons to do so, Wu himself explicitly acknowledges that attention's role in "selection for perception" is an outstanding question that his view on attention might help elucidate (2024). Another line of similarity is the temporal dimension of attention and purposive perception. Goal-oriented action and perception persist or wane over time. While in Camping Trip I experienced tactile habituation, I also need to keep my goal in mind, as it were, in order to find my keys in my backpack.

A preliminary remark. As I mentioned earlier, Wu's position emerges against growing scepticism over the past two decades over whether attention is a natural kind or singular process. He challenges us to accept his functional definition uniting the multiple processes underlying 'attention' since the alternative would entail undermining substantial scientific work on attention. It is not evident that this is a serious ultimatum scientists are facing. After all, as noted in the case of cognition, empirical research around attention would not stop without a broad consensus on what attention is. This should be instructive as to the importance and use of our Common Conception of active touch. What I take to be the importance of (re)definitional work in this context is to make sense of assumptions directing empirical research and to produce reasonable research queries for future work. The purpose-first reading of active touch can provide a principle of unification for the work of researchers whose investigations on active touch focused more on a given feature of the Common Conception. Although active touch tends to be object-oriented, coupled with movement and controlled, it is always purposive.

Attention sceptics in the scientific community (Hommel et al., 2019; Rosenholtz, 2024; Zivony & Eimer, 2021) are also helpful in reminding us that experimental paradigms should not be used to both infer that attention occurred and that attention was the cause of the observed behaviour. This should be true for our phenomenology of purposive behaviour as well: it does not follow that attention plays a causal role in purposive touch, or is identical to it, from the observation that examples of purposive touch are attended. It is also important to highlight here that our scientific understand-

[15] Thanks to one of the reviewers for challenging me to spell out the convergences and differences between the account presented here and Wu's view on attention.

[16] Interestingly, as Rosenholtz (2024) points out, when the explicit task of an experiment is to attend, observers mostly fail to process only the target.

ing of attention has been chiefly based on paradigms in vision and audition, although some gains have been made on tactile attention in the past two decades (see Spence & Gallace, 2007). The relative sparsity of research in the field of touch should give us pause when making modality-independent scientific claims on attention. This is important insofar as Wu's unified definition aims to grasp both our folk intuitions and the results of empirical findings.

One reason to persist in differentiating purposive perception from attended perception is that attention proves both too wide and narrow to capture purposive sensing. It is too wide if we consider attention to be a necessary ingredient for conscious perception (Jennings, 2020, Chp. 4; Prinz, 2000; Skrzypulec, 2022). On my purpose-first reading of active touch, not all cases of conscious perception are purposive, nor are all cases of attended touch goal-oriented. The temporal dynamics at play in Camping Trip might help make this clear. The surprisal of the first bug bite during the camping captures my attention, yet the experience of attentional capture is not goal-directed at first. Compare this with the case during camping trip where I follow the movement of the ant as it moves on my forearm. The early capture of attention toward the ant's undue presence is followed only, in a second step, by my goal-directed and attentive tracking of its movements. The dissociation conversely holds for top-down attention, as intuited earlier, the setting of the goal logically precedes the solution to the ways to achieve it. This does not exclude that purposive perception is a special case of attended sensing. However, I think that we should resist this conclusion as well.

It would be difficult to detail examples of purposive perception without at least some reference to attention. Yet attention is also too narrow to capture purposive touch and sensing. Active sensing, understood from the purpose-first perspective, is Janus-faced. If attention, understood as the timely solution to the selection problem might present one facet of purposive sensing, the latter also has an anticipatory facet. The conflation of expectation and attention is a problem in the empirical literature on perception as well: cued search paradigms for tracking attention manipulate the subject's expectation of the location of a likely target (Summerfield & Egner, 2009). This will be further developed in the following section with the role of outcome-tracking in purposive, active perception. Purposive sensing can thus be normative in the sense that its outcome can be fulfilled or not (Doyon, 2024). As Summerfield and Egner (2009) explain, the empirical difficulty between differentiating expectation from attention, hence the conflation, is that what is attended or expected is more readily detected than the unattended or unexpected. Yet, as they rightfully point out, we should be aware of the fact that the perceptual regularities that guide perceptual expectations are in principle orthogonal to our attending. This is more convincingly shown in later work that has empirically grounded this in principle distinction to show that we can dissociate expectation from attention to study the effect of one on the other (Kok et al., 2012; Summerfield & de Lange, 2014).

What does anticipatory outcome-tracking look like for our paradigmatic cases in touch? Another recent work by Miller et al. (2022) gives us grounds to think that touch localisation on the body can be computationally described through a probabilistic trilateration from the "anchoring points" (de Vignemont et al., 2009), that is the wrist and the elbow for the forearm. The reason why the estimation of the unknown point of contact is probabilistic is that noise is ubiquitous in the nervous system.

Their model for touch requires a Bayesian decoder to integrate the two estimates for identifying the point of contact since touch on the forearm occurs between two anchoring points.[17] This Poisson-like neuronal noise increases as one moves away from the anchor points. The signature of the Bayesian decoder for the localisation task generates a hypothesis that was confirmed by the researchers: if touch localisation on the forearm occurs via the integration of two estimates from either extremity, then localisation accuracy should be at its lowest away from the extremities, in line with the Weber-Fechner law. What this means for my purposes is that goal-directed perception in an uncertain world requires positing hypotheses whose outcomes matter to us.

5 Situating purpose in purposive sensing

There's still something vaguely unclear about purposiveness in sensing that will require further attention. What exactly is the purpose at play in this view on active sensing? Neither Gibson (1962) nor Prescott et al. (2011) are fully clear on what purpose is in active sensing. When Visell et al. (2016; see also Hartmann, 2009) attempt to capture this purposive character of active touch, they contrast the physiological character of passive touch (activation of mechanoreceptors by an external force) with active touch's physiological and 'psychological' nature. But what is psychological about purposiveness? The more obvious answer is that perception is purposive insofar as there is a conscious, intentional goal toward which information gain is oriented. Most of the examples of active touch that we have been considering so far have followed this line of logic: the perceiver was geared toward a particular perceptual aim whether in the case of Miller et al.'s experiment or in the paradigmatic exploratory procedures used by the perceiver to judge the texture, porosity, or rigidity of a surface. My aim, in this section, is to argue that we need to expand our understanding of this 'psychological' character of active touch. But first, we need to define this commonsense understanding of purpose in active perception.

When roboticists talk about purposive or goal-directed behaviour in the context of biomimetic models of perception, what they mean is often aligned with the influential Rubicon model of action phases (Achtziger and Gollwitzer, 2008). The Rubicon model takes its name from Caesar's crossing of the stream that marked the boundary between Italy and Gaul that, according to the tale, included a point of no return. What this motivational model aims to do is to answer the problem of the selection, enaction, and evaluation of motor goals by neatly dividing goal-setting and goal-striving as separate moments of goal-oriented behaviour. What marks the actional phase in this framework is a striving toward the formed intention in the deliberative process. Interruptions and setbacks are met with steadfast efforts to execute the action before a postactional phase where the success of the goal is evaluated.

[17] If these estimates are Bayes' optimal, provided a few tweaks, we can describe localization as $p\left(L|\,\tilde{L}\right) \propto p\left(\tilde{L}\middle|\,L\right)p\left(L\right)$, where p(L) represents prior information about the contact point's location, L the true point of contact, $\tilde{L}$ the estimate location and $p\left(L|\,\tilde{L}\right)$, the likelihood of the estimate $\tilde{L}$ given the true location L.

Three of the trailblazing roboticists behind the active perception program explain in a short history of the field that active perception consists in setting up "a goal based on some current beliefs about the world and to put in motion the actions that may achieve it." (Bajcsy et al., 2018). To see the similarity with the way roboticists and some motivational psychologists understand purposive behaviour, take their example of a perceptual system whose aim is to make a Greek salad (ibid.). This system for them is active because it (1) knows why it wants to sense, i.e. toward the ultimate goal of making a salad, (2) it chooses what to perceive in relation to the top-down goal, and (3) finally it determines how, when and where to achieve that perception. Following the deliberation phase, Gollwitzer's preactional phase includes planning concrete steps for achieving the goal and Bajcsy, Aloimonos, and Tsotsos echo this in their example: "The agent has a plan—or knowledge—of what is needed to produce the salad." If a knife goes missing once the action phase has started, the agent can then either move in order to get a different, better view or modify the scene by moving objects around. This adjustment is defined by the agent's intent and regulated by top-down attentional processes. This is the earmark 'striving' of the actional phase of the Rubicon model. It also serves as a good indication of our struggle in situating the role of bodily movement in active touch since any required movement can only gain sense in relation to the overarching purpose. Finally, and along the same lines, the authors argue that the best control strategy is determined in relation to the current goal of the agent. Designing a system with a laser range finder to discriminate bigger objects from smaller ones for example (Tsikos & Bajcsy, 1991) will require much more detailed top-down feedforward control than in an open-ended exploratory task.

The active sensing literature in robotics has since its inception aimed at taking insights from human perception to develop better non-human perceptual systems. Indeed, these roboticists often cite Gibson's ecological psychology as a key inspiration for their approach. I have argued that the notion of intent and active perception that they developed can, in turn, help us better understand the purposiveness human perception. Nonetheless, to be applied to humans, this characterisation of active touch requires three further specifications:

1. Conscious purposiveness does not exhaustively capture active touch.
2. The mark of goal-directedness is outcome tracking.
3. Single goal-directedness of behaviour is often a (useful) abstraction.

First, as a consequence of what was previously said, it might be assumed that all active sensing is guided by conscious, intentional purpose. However, this is not the case. The guiding intuition is reasonable: a simple way of finding out if a behaviour is goal-directed and the nature of the goal is to ask the agent. Motivation researchers often derive goals and their contents by analysing the content of participants' reported thoughts (e.g., Gollwitzer, 1990, 68). The assumption at play here is that purposive behaviour or perception is defined by the mental states that can, in the final analysis, explain it. Purposive perception can even require two different mental states: a desire for a particular end and a propositional belief that describes how one should get there. Our previous examples often capture this thought. The best way for the participant in the Miller et al. experiment to localise touch on the tool in the so-called passive condition is to direct her attention toward the vibration stemming from the rod. To understand what the salad maker is doing, it seems tempting to take an intentional stance and claim that it desires to make a salad and has a plan that describes how to make it, including strategies to tackle unexpected hurdles.

Although this is plausible in many paradigmatic cases there are reasons for broadening our scope of purposive sensing beyond restricted reflexive cases. The first one is that we do not always have the appropriate awareness of the reasons guiding our purposive perception. Suppose that while going up a climbing wall, I slip and briskly attempt to grab a hold. There might be good reasons for it: even though I am belaying, and the floor is padded with a safety mat, I might still rather avoid an awkward fall that can leave me sore. My decision can even be sensitive to a combination of reasons, I might be more averse to experiencing the fall if the floor is padded but that I don't have a belay rope. Although all this and more can be candidates for a plausible explanation for my reaching for the hold, it is yet more likely that I only have vague awareness of them at the moment I hang on for dear life. That is, my reaching can be information-based but prereflexive.[18] Moreover, beyond this appeal to intuition, there is shockingly little in terms of evidence for reflexive deliberation as the generative cause of motor control (Kunde et al., 2012; Schouppe et al., 2014; Hommel, 2022, 1057).

Second, if we cannot appeal at all times to the accessible mental goals of the agent, how do we come to define what her goals are? Part of the answer is, as seen in the previous section, that active touch involves anticipatory outcome tracking. This is an insight gleaned from the comparator models of action control that have stressed the role of comparing outcomes with internal goals to explain behavioural learning and optimisation (Ridderinkhof et al., 2004). This feature of active touch is already implicitly present in some of the active sensing robotics literature previously surveyed. As Hartmann (2009, 687) notes, one of the features of passive touch is that it is often temporally unexpected. This characteristic of passive touch can be seen in one of the previously mentioned examples: as I hold on to the handrail while walking up a set of stairs, I *suddenly* feel my friend falling behind me. Active touch can also include some form of surprise with the important difference that this surprise is relative to hypothesised outcomes based on the goal(s). Although beyond the scope of this paper, there is neuroscientific evidence that not only do we track the outcomes of our own goal-directed perception, we outcome-track the active sensing of others as well (Costantini et al., 2014; Donnarumma et al., 2017).

Third, one ambiguity is left unresolved from our discussion on active touch due to the paradigmatic examples used. The examples often represent a simplification of goal-directed behaviour given that the human and nonhuman perceptual agents focus on a singular goal at a time. *The* goal of the participant in the Miller et al. experiment was to localise touch on tool in the same way as *the* goal of the active sensor in Bajcsy, Aloimonos, and Tsotsos's example is to make a Greek salad. What seems

[18] Much of this is inspired by Stephen Butterfill's (2001) distinction between two types of purposive action, one mentalist the other teleological. I claim here that there can be at least two types of purposive sensing as well. One important point where my analysis diverges from Butterfill's is in his distinction response behaviour and purposive action. He claims that only the latter requires a rationalising explanation but as I claimed in 2.2. automaticity and other-generated actions are not always goal-free.

more likely, in a natural setting, is that goals are plural and sometimes inconsistent. Thus, target selection involves a multiple-constraint-satisfaction process that tries to satisfy multiple goals (Hommel, 2022, 1066). The participant in the Miller et al. experiment might be guided by the goal of localising touch on the rod as well as entertaining the (in)compatible goal of wanting to be done with the experiment in time for lunch. What implications does this have for our characterisation of active touch? For one, the earlier (Sect. 3.3) comment from Lederman and Taylor that the touching process should be considered more or less "active" seems to gain credence. Touch is more or less active as a consequence of the motivating force behind the pursued goal. This does not mean that we should give up on goal identification, I can very easily anticipate that my peer wants to reach for a small object because of the preshaping of her hand in a precision grip (Ambrosini et al., 2011). This seems plausible: even though I have reasonable intuitions for thinking that this is the main reason for her reach-to-grasp movement, I do not exclude other goals from motivating her gesture, e.g., that she is reaching for the light switch because the room is too dark. Conversely, the idea that sensing could be guided by no goals at all seems to be a helpful abstraction, but we should not conclude therefrom that this is an accurate representation of action control at a finer-grained level of analysis. Camping Trip helps us better capture this final point about active touch in the natural setting: it is only at the very beginning that I purposefully track the movements of the bug and at the very end of my trip that I complete stop paying attention to its movements. In between, I feel the force of habituation slowly transform what initially was active touch into passive touch.

6 Conclusion

My goal in this paper was to demonstrate that active touch should be understood as foremost purposive and goal oriented. Although my amendment to the Common Conception of active touch might have seemed to undermine the role of bodily movements in perception, my aim was more to better define its role in goal-directed and information-seeking perception. I maintained that the upshot of my account is that it allows for a more refined understanding for the role of bodily movement in the experience of tactual sensing. This allowed a coherent explanation as to why, even in the passive task used by experimenters, the participants' ability to localize touch on the tool remained highly above chance levels (Miller et al., 2018). As I suggested in the introduction, the notion of activity that I developed here could be beneficial to other sensory modalities as well besides haptic exploration. Finally, I proposed three specifications to better capture the application of the robotics' understanding of active sensing to active touch to humans. The three key refinements—recognizing that conscious purposiveness is not exhaustive, identifying outcome tracking as the hallmark of goal-directedness, and acknowledging the utility of simplified goal-oriented abstractions—provide a pathway for applying the insights from robotics to our understanding of active touch.

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Declarations

Conflict of interest The author has no conflict of interest to declare.

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