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研究課題名（和文）Is active perception better than passive perception? Examining the role of action in perception through a systematic literature review and comprehensive behavioral experiments

研究課題名（英文）Is active perception better than passive perception? Examining the role of action in perception through a systematic literature review and comprehensive behavioral experiments

研究代表者

ＳＡＮＧＡＴＩ　Ｅｋａｔｅｒｉｎａ（Sangati, Ekaterina）

沖縄科学技術大学院大学・神経計算ユニット・ポストドクトラルスカラー

研究者番号：７０８９８２４６

交付決定額（研究期間全体）：（直接経費）　　3,500,000円

研究成果の概要（和文）：本研究は、能動的知覚と受動的知覚の利点を系統的文献レビューと行動実験で探求しました。レビューでは、四つの感覚モダリティから86件の関連研究を特定し、知覚結果をタスクの具体性に関連付けました。能動的知覚は一般に知覚精度を向上させますが、結果は感覚モダリティやタスクによって異なりました。行動実験では、ロボットアームと感覚代替装置を用いた2Dオブジェクトのサイズ推定を行いました。認知的関与が知覚精度を向上させることが示されましたが、能動的探索と受動的探索の間に有意な差は見られませんでした。包括的な研究には改良された実験インターフェースが必要です。

研究成果の学術的意義や社会的意義
The research advances understanding of how active and passive exploration impact perceptual performance, contributing to cognitive science. It also informs the design of perceptual interfaces, sensory substitution devices and rehabilitation programs.

研究成果の概要（英文）：This project explored the benefits of active vs. passive perception by means of a systematic literature review and a behavioral experiment. Our systematic review identified 86 relevant studies from four different sensory modalities. We extracted data that allowed us to relate perceptual outcomes to task specifics and found that while active perception generally improves perceptual accuracy, results vary significantly by sensory modality and task. In our behavioral experiment, we used a 2D object size estimation task with an interface composed of a robotic arm and sensory substitution device. Results indicated that cognitive involvement enhances perceptual accuracy, but no significant difference was found between active and passive modes of exploration. The study also highlighted the need for improved experimental interfaces for more comprehensive research.

研究分野：embodied cognition

キーワード：active perception　systematic review　perceptual interfaces　size estimation

1．Background of the project 研究開始当初の背景

Traditional work in cognitive science has assumed that adaptive behavior is realized through a series of neatly separable steps. First, stimuli are passively received by the sensory organs (input). Then, information is processed in the brain (computation). Finally, motor activity is executed by the body (output). An alternative view, known as *embodied cognition*, has been developed. This view holds that 1) cognition is done by the whole body situated in the environment, 2) different parts of the cognitive process are intertwined and 3) *perception is active*, i.e., exploratory activity is essential for our ability to perceive or at least enhances perception (Gibson, 1986; Clark, 1998; Varela et al., 1991).

The superiority of active perception has been extensively studied in both regular sensory modalities (mostly vision and touch) as well as new perceptual interfaces called sensory substitution devices (SSD). In SSDs, one type of sensory information (e.g., sound intensity) is delivered through another sense (e.g., vibration on the skin). For both types of perception, *empirical evidence regarding active perception has been contradictory*. Some studies have shown the advantage of active perception (Heller, 1989), others have shown the advantage of passive perception (Magee & Kennedy, 1980), and yet others have found no difference (Lederman, 1981). Furthermore, there is ongoing discussion about *what specific component of action is necessary or beneficial for perception* (Figure 1). Some researchers stress the importance of dynamic relational information made available by movement (Gibson, 1986; Turvey, 2018), others emphasize specific motor activity (O'Regan & Noë, 2001), and others still focus on higher-level active regulation such as goal-directedness or attention focus (Prescott et al., 2011). Finally, it remains unclear *which specific aspect of perception is most affected* by different modes. The main advantage of active conditions might lie in greater *perceptual accuracy*, or in *perceptual experience*, for example, making a novel perceptual interface feel more natural.

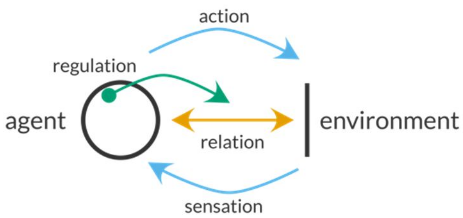

Figure 1: Active perception elements.

2．Purpose of the project 研究の目的

The aim of the project was to bring conceptual clarity to the active perception debate by answering the question "*Is active perception better than passive perception?*" in two steps.

First, we planned to conduct a *systematic review* of studies comparing active and passive exploration conditions on perceptual outcomes in various sense modalities. This would allow us to comprehensively assess *under what conditions active perception is better*, specifically, depending on the types of tasks, stimuli, and on how active and passive exploration are operationalized. Including multiple modalities was intended to provide a view on active perception that goes beyond the specifics of a particular sense like touch or vision. Currently, no such review is available in the field of active perception, which likely hinders both theoretical and empirical progress.

Second, we intended to conduct two *behavioral experiments* that compare active and passive perception in the most controlled and systematic way possible, thereby overcoming some of the methodological limitations of previous studies. The first study aimed to determine *which components of active perception matter for perceptual outcomes*, specifically distinguishing between the role of motor information and the role of specific perceptual goals. The second study aimed to explore *which aspects of perception are affected by active compared to passive exploration*: behavioral performance or experiential quality. For both studies, we planned to design an experimental apparatus that tests different types of stimuli (2D, 3D, etc.) and tasks (size estimation, shape recognition, etc.) and enables the passive condition to match the active condition as closely as possible. This would result in a *methodological contribution* to the field in addition to empirical findings.

３．Research method 研究の方法

The systematic review was conducted following standard methodology: 1) Identify databases to search for relevant literature, 2) Define search keywords, 3) Create a database of articles that match the keywords, 4) Complement the automatic search with manual search (forward and backward search, expert consultations), 5) Prepare a protocol for selecting relevant articles (through automatic filtering and manual assessment), 6) Review articles for relevance based on a) titles and abstracts and then b) full text, 7) Define the dimensions grid for data extraction, 8) Extract the data, 9) Perform qualitative and quantitative analysis. We pre-registered our methodology and followed the PRISMA protocol for systematic reviews, ensuring that our review steps were documented and that our procedures allow other researchers to assess our evidence base and results. Although we had not originally planned to evaluate included studies for quality, we added this element to comply with PRISMA guidelines.

The experimental part of this research involved a setup that combined a robotic arm Torobo, a sensory substitution device (SSD), and a physiological recording system for measuring electromyographic (EMG) activity. The robotic arm allowed us to record exploratory trajectories of participants in the active condition and play them back to participants in the passive condition. Our SSD was the Enactive Torch (ET) which translates distance measurement captured by an infra-red sensor into a proportional vibration intensity of a small coin motor. Using the ET, one can perceive object shapes at a distance without seeing or touching them. We opted for using the ET rather than a regular perceptual modality like touch to 1) create a less familiar perceptual context, which might enhance potential differences between conditions, 2) implement a sensory-motor loop more amenable for experimental manipulation, and 3) study the development of perceptual skills, not just their exercise. Finally, we synchronized an EMG signal recording system with the Torobo-ET interface to monitor the level of motor activation in different experimental conditions.

In the first study, referred to as the Agency Experiment, we tested whether active perception delivered better behavioral performance than passive perception. Participants were asked to estimate the width and height of differently sized 2D objects using the ET slotted into a robotic arm (Figure 2). In the Active Condition, participants moved the robot to explore the objects, and the resulting movement trajectories were recorded. In the Passive Condition, the robot replayed these trajectories to a different set of participants. To ensure passive participants were not exerting any effort, muscle activity of the biceps was recorded. Furthermore, *the knowledge of the exploration goal* was manipulated. In some trials, participants were told in advance that their goal was to estimate width or height (Specific Intention condition). In other trials, they were told to simply explore the object (Generic Intention condition). In both cases, the post-exploration question was to estimate width or height of the object by drawing a line on a touch screen and we recorded the response as the Euclidean distance between the starting and end points in xy-coordinates. We derived two accuracy measures: Actual-Estimate Correlation, expressing how distinct the different object sizes appeared, and Percent Variable Error, capturing how consistently each size was perceived. Finally, we performed a mixed ANOVA to analyze the effects of exploration and intention type on perceptual performance.

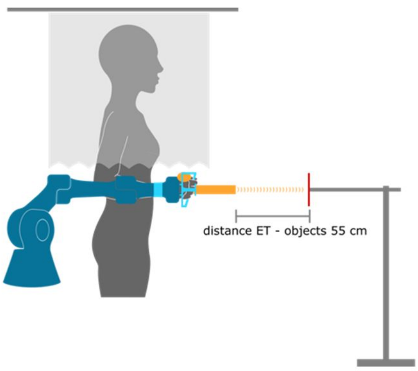

Figure 2: Agency experiment setup.

The second experiment, intended to test the impact of exploration on experiential quality of perception, had to be aborted due to inherent limitations of our implemented interface uncovered during the first experiment (described below).

4. Research outcomes and possible impact 研究成果

Systematic Review identified 7,239 matching articles that were screened for relevance by independent reviewers based on title and abstract, and then based on full text. In the final stage ,data was extracted from 86 studies involving a total of 2,634 participants. These studies contained active and passive conditions from four sense modalities: touch, vision, hearing and proprioception. The results were integrated with a modest quantitative approach focused on features characterizing implemented tasks and manipulations, and a qualitative narrative synthesis. Our analysis showed that active perception generally improves perceptual accuracy (Figure 3). However, this active advantage varies with sensory modality and task specifics. For instance, in touch, active exploration often led to better shape recognition, whereas in vision, active head movements improved depth perception. Conversely, certain passive conditions demonstrated comparable effectiveness, particularly when stimulus dynamics were preserved. Overall, our

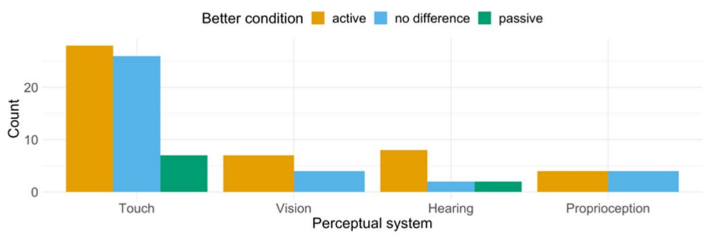

Figure 3: Systematic review overall results.

investigation highlighted considerable methodological and theoretical diversity, indicating a pressing need for more conceptual development and empirical research better informed by existing paradigms in different perceptual modalities.

The Agency Experiment found that perceiving the object under Specific Intention conditions led to higher accuracy than under Generic Intention, indicating that cognitive involvement in the perceptual process is an important element of active perception. We analyzed specific exploration trajectories in these conditions and found that participants tailored their movement to the task. Specifically, they explored primarily horizontal or vertical dimension when they knew the task was to estimate the object's width or height, respectively. When instructions were generic ("explore the object"), they moved in both dimensions. Thus, intentions guide how perceptual information is sampled from the environment, affecting task performance accuracy.

Our results with respect to the Active and Passive exploration mode were less conclusive. EMG analysis confirmed that passive participants showed very little muscle activity, indicating that our manipulation was successful. However, we found no main effect of exploration mode on perceptual accuracy, suggesting that motor production is not relevant for the task of size estimation in our settings. At the same time, considerable individual variability between different pairs of participants likely contributed to the lack of a significant group-level effect of exploration condition. Some pairs showed worse performance by the passive participant, others by the active participant, and others showed no difference. The source of this variability requires further investigation. Another possible explanation for the lack of active-passive effect is that information for 2D size estimation is available in both exploration conditions (e.g., movement velocity perceived via proprioception), supporting the view that the role of action in active perception is to provide dynamic relational input, regardless of how it is obtained.

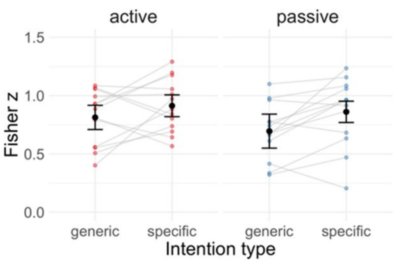

Figure 4: Agency experiment results.

The experiment also tested our experimental interface, revealing issues in two critical aspects: 1) usability of the robot arm, and 2) accurate synchronization between components. The robot arm, chosen for its ability to record and play back trajectories, was difficult for participants to move in paths other than vertical or horizontal, limiting its use for more general tasks. Synchronizing data between the robot trajectories, ET distance sensor and motor output, and physiological recording system was challenging due to heterogeneous hardware and software implementations. A more unified system is advisable for future research.

The study of active perception pursued in this project has broader practical implications in helping design better sensory substitution devices and other technological interfaces, or sensory and motor rehabilitation programs. Our research pointed at specific areas in which more theoretical, methodological, and empirical research is required to advance this field.

5．主な発表論文等

〔雑誌論文〕　計2件（うち査読付論文　2件／うち国際共著　2件／うちオープンアクセス　1件）

1．著者名 Sangati, Ekaterina; Lobo, Lorena; Estelle, Stephen; Sangati, Federico; Tavassoli, Samira; Froese, Tom	4．巻 45
2．論文標題 Uncovering the role of intention in active and passive perception	5．発行年 2023年
3．雑誌名 Proceedings of the Annual Meeting of the Cognitive Science Society	6．最初と最後の頁 663-670
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
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1．著者名 Sangati, Ekaterina; Stromberg, Mats; Sangati, Federico; Lobo, Lorena	4．巻 Submitted
2．論文標題 Active and passive perception in several sense modalities: Systematic review	5．発行年 2024年
3．雑誌名 Journal of Experimental Psychology: General	6．最初と最後の頁 -
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
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〔学会発表〕　計1件（うち招待講演　0件／うち国際学会　1件）

1．発表者名 Sangati, Ekaterina
2．発表標題 Uncovering the role of intention in active and passive perception
3．学会等名 Annual Meeting of the Cognitive Science Society（国際学会）
4．発表年 2023年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関