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FEATURE STORY

Developing Visual Information Processing Technology through Human Exploration

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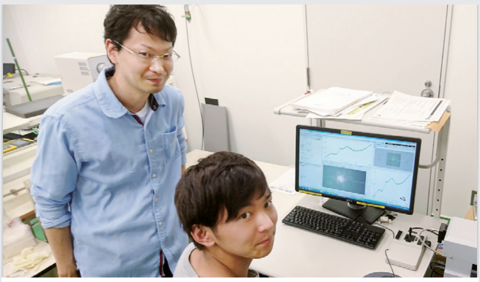

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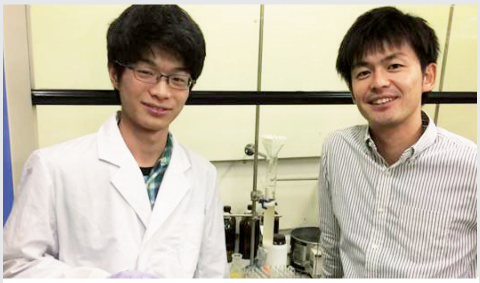

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Developing Visual Information Processing Technology through Human Exploration

Shigeki Nakauchi

Today we are living in an age of articial intelligence (AI), where it is feared that someday soon computers may threaten our jobs as they gradually surpass human ability. But is technological singularity really something to worry about? Prof. Shigeki Nakauchi says that the key to this answer lies in the differences between AI and humans. Prof. Nakauchi, who is an expert in the function of the brain that controls visual perception in humans and its mechanism, explains that, "while they differ from one another in that one is made up of protein and the other of semiconductors, brains and computers are similar in that they are both made up of substances, and there is no guarantee that there are things only humans can do. However, there are at least big differences in what humans and computers can do at present." Prof. Nakauchi is trying to gain a glimpse into a future where humans and AI may coexist by addressing the fundamental question of what it means to be human.

Interview and report by Madoka Tainaka

Exploring human brains and functions for coexisting with machines

Prof. Nakauchi became interested in computers when he was a middle school student and the computer boom was just beginning. He entered a technical college (KOSEN) hoping to research information engineering, but eventually turned his attention to biology. This was because he was driven by an interest in testing the limitations of machines and finding out how they differ from humans as living beings. For Prof. Nakauchi the key to these questions was to focus on learning about human beings.

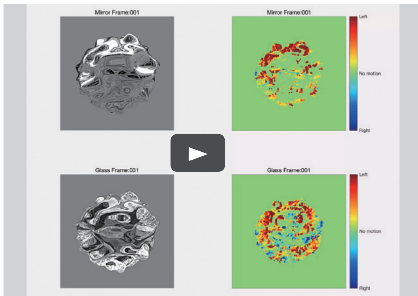
Prof. Nakauchi is still inspired by these questions. The current debate in this field focuses on the possibilities thrown up by the third AI boom that the singularity (a hypothetical technological singularity when AI supersedes the human brain) may be within reach. In this context, Prof. Nakauchi believes that researchers should be focusing on the differences between machines and humans and in particular how machines and humans may communicate with each other.

"Computers are able to compute much more data than the human brain at much faster speeds, but generic AIs that supersede human ability are not likely to be developed for some time. On the other hand, humans are gradually adapting to a society that utilizes a plethora of machines. As one example, the Internet now serves as an external memory device for humans, meaning that we no longer need to remember maps or unfamiliar words. This causes the brain and society to change with it.

The trend towards ever greater human-machine coexistence appears unstoppable. In order to prepare for such a future, my goal is to uncover how to achieve optimal human-machine relations by conducting an in-depth study of humans."

How do humans distinguish between "textures"?

Broadly speaking, Prof. Nakauchi's research can be divided into two categories. The first is the basic groundwork of "scientifically studying visual perception" with the aim of uncovering visual function. The second involves consolidating the findings obtained through this basic research and seeking technological applications, in other words "applying visual perception as technology". Recently, in particular, this basic research has produced a string of ground-breaking discoveries, the results of which have been published in international journals[1]. One such study, relating to "distinguishing between textures" using visual perception, uncovered what humans use to distinguish between "reflective materials" such as mirrors and polished metals which produce a reflective effect through light reflecting on the surface and "transparent materials" such as glass and ice through which light passes and refracts.



Mirror/glass object (left-hand column) and dynamic information when objects are rotated to the left (right-hand column). The glass material contains more components moving in the opposite direction (right) to the rotation direction (left)

According to Prof. Nakauchi, "humans have good eyes and can discriminate slight differences between various materials. For example, humans can tell that a desk which looks like wood is actually made of plywood, or whether or not leather is real. The same applies to glass and metals, with humans being able to distinguish between these materials even if they have complicated shapes. However, light reflects only on the surface of metal materials and is partially absorbed by and scattered in glass materials, meaning that these materials have no color of their own and merely distort and reflect whatever is around them. Up until recently, it wasn't clear what humans used to distinguish between the two."

Prof. Nakauchi and his team generated images using computer graphics that looked like either metal or glass and had participants say which material they thought the picture looked like. The team noted that the participants found it easier to discern the material when the object rotated rather than when they viewed a still image. Through controlling the shape and movement components of the objects to see how differently people perceived them, they achieved truly fascinating results.

"We found that, with metals, light reflection moves in the same direction as the rotation of the object, but glass reflects transmitted light and has some component in which light reflection moves in a direction opposite to rotation of the object. We also discovered that information on movement is not just used for distinguishing between materials but also gives materials that real feeling of being metallically shiny or transparent."

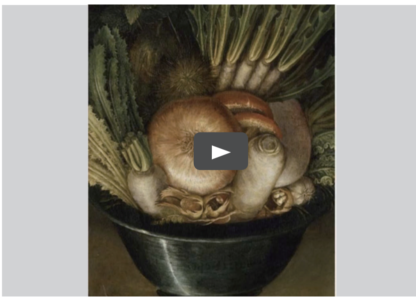
Interestingly enough, Prof. Nakauchi stated that humans tend to treat translucent materials such as marble or jade as important and expensive. This is why many bottles used for expensive cosmetic products are translucent.

"If we can further investigate what humans use as clues to distinguish between textures, such findings could be useful for future product development," suggests Prof. Nagauchi regarding possible outcomes of his study.

Humans subconsciously determine "face-likeness"

Studies concerning the face are also of great interest. People not only have the ability to determine that a person is still the same person despite a change in expression, hair style or clothing but can also determine "face-likeness" in car bonnets and paintings made up of objects, such as Arcimboldo's portraits using fruit and vegetables. Because we need to be able to recognize faces for communication within society, humans are believed to be very good at discerning faces.

In order to investigate the visual information processing that takes place when a human looks at a face-like object, Prof. Nakauchi and his team measured brain activity and brainwaves when a subject was shown an object that looked like a face and studied the stage at which face-likeness recognition occurs[2]. All studies used black and white images which were pictures of human faces, as well as cars, bugs, paintings by Arcimboldo, and other objects. Participants were also shown upside-down images.



Sistema Museale della Citt à di Cremona -Museo Civico "Ala Ponzone"/Museo Civico "Ala Ponzone"-Cremona, Italy

"The results of the brainwave measurement indicated that face-likeness is first processed at a very early stage of around 100ms, a face is detected at around 170ms, and expressions and individuals are identied at 250ms, meaning that facial recognition occurs in three stages. In addition, when a face is rotated, facial recognition slows to the same speed as when a face-like portrait is viewed, which tells us that processing patterns vary depending on how much an object looks like a face."

In the initial stage of the first 100ms after viewing an object the processing appears to be instinctive rather than being consciously controlled. In other words, humans almost instantaneously take note of face-likeness, even before they are aware of what the object is.

Prof. Nakauchi explains that, "We believe that face-likeness recognition is most likely an inborn function, which can be seen in how a baby needs to recognize the face of its mother to survive."

Does inspiration occur before we are aware of it?

Prof. Nakauchi also studies the "science of inspiration," which is a subject unique to his team. Through studying the time at which inspiration occurs by measuring pupils, which are said to represent a person's mental state, the team made the remarkable finding in tests that the participants' pupils began to dilate before they were consciously aware of particular thoughts[3].

"We showed participants 6-second videos of black and white dots that moved and changed density to depict various images, like a coffee cup. The video was stopped at 1.5 seconds and participants were asked whether or not they recognized the object. Then, the video was resumed and played until the end and participants were asked the same question again. The people who answered "no" when asked the question at the 1.5 second mark provided us very interesting results. Those who answered "no" then but went on to figure out the object after watching the whole video presented pupil dilation before the one second mark. In other words, their brain had begun the process of piecing together memories even though they were not aware of this. Meanwhile, the participants who failed to recognize the object even after viewing the entire video presented little pupil dilation."

People often experience times where they can picture someone's face but their name remains on the tip of the tongue. This kind of phenomenon may be one instance of knowing the answer but not being conscious of that knowledge.

Prof. Nakauchi says that, "applying these findings may make it possible in the future to measure how much people understand by measuring their pupils or to support memory retrieval by externally controlling pupil dilation." Future applied research is also expected to yield exciting results.

[Reporter's Note]

Now in his 50s, Prof. Nakauchi wants to focus on the themes that really touch his heart for the remainder of his career as a researcher. Wanting to ask the simple but big questions that have largely been neglected by science, Prof. Nakauchi now turns his attention to studying how perceptions such as preference, novelty and intimacy, which affect human behavior and decision making, are generated. "Studying aesthetics falls under this category. Why do we feel that pieces of art by famous artists are good? How do we spot a fake? It's quite a mystery, isn't it?

Also, since I was in a brass band as a student and am now a member of a choir for my local opera, I'm also interested in finding out the state of the brain when humans are in synch or have fostered a sense of unity when playing music or a team sport together. Figuring this out should definitely prove to be useful for coexisting with robots as well."

Evidently, Prof. Nakauchi still has a lot of interesting topics to sink his teeth into along his way to finding out what it means to be human.

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人間を深く知ることで、視覚情報処理技術の開発をめざす

人工知能（AI）が人間の能力を超え、近い将来、人々の職を奪うのではないかと危惧される昨今。はたしてそのような「シンギュラリティ」は、本当に訪れるのだろうか。その答えのカギは、「AIと人間の違いにある」と中内茂樹教授は語る。人間の視覚を司る脳機能や、そのしくみの解明を試みてきた中内教授は、「タンパク質と半導体の違いはあるにせよ、脳もコンピュータも物質から成るという点では同じであり、人間にしかできないことが存在する保証は何もない。ただ、少なくとも現状はできることに大きな違いがある」と語る。人間をより深く知ることで、AIと人間が共存する未来の姿を探ろうとしている中内教授に話を聞いた。

機械との共存のために、人間の脳や機能を探りたい

中内教授は、中学生の頃、当時、勃興期にあったコンピュータに惹かれ、情報工学の研究者をめざして高等専門学校に進学した。やがてその関心は生物学へ向かう。機械にできないことは何か、機械と生物（人間）は、何がどう違うのか、それを解明するためには生物をより深く知る必要がある、という思いに駆られたためだ。

その興味は現在も変わらない。むしろ、第3次AIブームを背景に、シンギュラリティ（AIが人間の脳を超えるとされる技術的特異点）がさかんに議論されるいまこそ、人間と機械の違いや両者のコミュニケーションのあり方について、科学者が方向性や可能性を示すべきだと中内教授は言う。

「膨大かつ高速の計算など、コンピュータが人間をはるかに凌ぐ領域はありますが、人間を超える汎用的なAIはまだまだ開発されそうにありません。一方で、人間は機械の溢れた社会に柔軟に適応して変わりつつある。たとえば、インターネットはいまや人間にとって外部記憶装置としての役割を担い、私たちは地図や知らない単語などをいちいち覚えておく必要はありません。それに伴い脳も変わるし、社会も変化しています。

今後ますます人間と機械の共存が不可避である以上、人間をより深く知ることで良い関係性を探り、最適なシステムを提示したいというのが私の研究のモチベーションになっているのです」

人間は「質感」をいかに見分けているのか

中内教授の研究は大きく分けて、視覚機能の解明をめざして「視覚を科学する」基礎研究と、基礎研究で得られた知見を技術として結晶させる「視覚を技術する」応用研究の二つに分けられる。

とくに最近、前者の基礎研究において相次いで画期的な成果を生み出し、国際ジャーナルに発表した。その一つ、視覚の「質感の見分け」に関する研究では、鏡や研磨された金属のように光が物体表面で鏡面反射する「反射物質」と、ガラスや氷のように光が物体を透過したり屈曲したりする「透過材質」について、人間が何を頼りに判別しているのかを明らかにした。

「人間の目は優れていて、この机は木目に見えるけれど合板だなとか、この皮は本物だなといった具合に、さまざまな物質の微妙な違いを見分けることができます。ガラスと金属についても同様で、それらが複雑な形をしていても判別できるでしょう。ところが、金属は表面のみで光が反射し、ガラスは光の一部が物質に吸収されて散乱するので、材質そのものには色はなく、周りの景色が歪んで写り込んで見えるだけです。これまで人間がいったい何を手掛かりにこれらを見分けているのかがわからなかったのです」と中内教授は説明する。

そこで中内教授らは、コンピュータグラフィックスで金属とガラスそれぞれに見える画像を生成し、実験参加者に金属とガラスのどちらに見えるかを聞いた。その際、静止画像よりも回転している動画のほうが見分けがつきやすい点に着目。物体の形状や動きの成分をコントロールすることで、見え方の違いを調べたところ、興味深い結果が得られた。

「じつは金属では、物体が回転する方向と同じ方向に光の反射が動くのですが、ガラスでは透過した光が反射して、物体の回転とは逆方向に動く成分も存在することがわかりました。また、そうした動きの情報は、材質の見分けに使われているだけでなく、キラキラとした金属感や透明感という材質のリアリティを生み出していることもわかったのです」

興味深いことに、中内教授が、人間は大理石や翡翠など、半透明なものを大切なもの、高級なものと感じる傾向があると教えてくれた。だから、高級化粧品には半透明なボトルが採用されていることが多いのだという。

「人間が質感を見分ける手がかかりをより詳細に解明できれば、こうした知見を将来的には商品開発などに役立てることができるかもしれません」と、中内教授は研究の出口についても示唆した。

人間は無意識に「顔らしさ」を判別している

「顔」に関する研究も興味深い。人は、表情や髪型、スタイルなどが変わっても同じ人だと判別できるだけでなく、果物や野菜などを寄せ集めて肖像画を描いたアルチンボルドの絵や、車を正面から見た場合も顔らしいと感じる。顔の認知は社会的コミュニケーションに不可欠であることから、人は顔の認知に敏感だと考えられる。

その際に行われている人間の視覚情報処理を探るために、中内教授らは「顔のように見える」物体を見たときの行動と脳波を計測し、顔らしさの認知がどの段階で生じるのかを調べた。なお、実験にはいずれもモノクロ画像で、人間の顔のほか、車や昆虫、アルチンボルドの絵などを用い、それらを逆さまに提示した場合についても調べた。

「脳波の計測の結果、まず100msという非常に早い段階で顔らしさを処理し、170msくらいのところで顔を検出、250msで表情や個人を特定するという、三段階で顔の認知を行なっていることがわかりました。また、反転させた場合、顔らしい絵ほど処理が遅れるなど、顔らしさの程度によって処理のパターンが変化することもわかりました」

100msというと意識的に処理をコントロールする前の段階である。つまり人は、物体像が意識にのぼる前にほぼ自動的に顔らしいものに注意を向けているのだ。

「赤ちゃんにとって、お母さんの顔の認識が生命をつなぐのに欠かせないように、おそらく顔らしさの認識というのは人間に生得的に備わっている機能と考えられます」と中内教授は言う。

「わかった！」と思うよりも前に、人はひらめいている!?

さらに、「ひらめきを科学する」というユニークな研究も行なっている。人の精神状態を表すとされる瞳孔の変化を計測し、ひらめきがいつ生じたのかを調べたところ、実験参加者がひらめいたと意識するよりも前に瞳孔が開き始めるという、非常に興味深い知見を得た。

「提示したのは、モノクロのドット（点）が動いて、密度が変化することでコーヒーカップなどのイメージ画像を描く6秒間の動画です。その際、1.5秒でいったん動画を止め、わかったかどうかを聞き、その後、動画の続きを最後まで再生して、ふたたびわかったかどうか尋ねます。

面白かったのは、1.5秒でわからないと答えた人たちです。その時点ではわからないと答えた人も、最後まで動画を見てひらめいた人の場合は、1秒より前の段階から瞳孔が開き始めていたのです。つまり、本人は自覚していないけれど、じつは脳では記憶照合のプロセスは始まっていたことになる。一方、最後までわからなかった人の瞳孔の開きは弱いままでした」

よく、顔が浮かび、喉元まで名前が出かかっているのに、なかなか答えられないということがある。これなども、意識が届かないところでは答えがわかっているのだろう。

「この発見を応用することで、今後は瞳孔から人の理解度を測ったり、瞳孔の開きを外部からコントロールすることで、記憶の検索を支援したりすることが可能になるかもしれません」と中内教授。今後の応用研究にも大いに期待が膨らむ。

（取材・文＝田井中麻都佳）

取材後記

現在、50代の中内教授は、残りの研究者人生を、心の底から惹かれる、そんなテーマに打ち込みたいと語る。たとえば、嗜好性、新規性、親密さといった、人間の行動や意思決定に影響を与える感覚がどのように生じるのか、これまであまりサイエンスの俎上に載らなかったような、素朴で重大な疑問に迫る研究をしたいと言う。

「審美眼の研究もその一つ。なぜ偉大な美術家の作品をいいと思えるのか、なぜ贋作だとわかるのか、不思議ですよね。

もう一つ、私は学生時代、吹奏楽に打ち込み、現在は市民オペラで合唱団の一員として活動しているのですが、音楽の合奏やチームスポーツなどで、一体感が醸成されたり、息の合ったプレイができたりしたときの脳の状態についても探ってみたい。それがわかれば、人間とロボットの共存にも、必ず役立つはずです」と中内教授。

中内教授の人間を探る研究は、ますます面白味を増しそうだ。

Researcher Profile

Dr. Shigeki Nakauchi

Dr. Shigeki Nakuchi received his B.A., M.S., and PhD degrees in information engineering in 1988, 1990 and 1993 respectively from Toyohashi University of Technology, Aichi, Japan. He was a visiting researcher at Lappeenranta University of Technology in Finland from 1998 to 1999. Since 2002 and 2007, he has been a visiting researcher and a visiting professor at Brain Science Institute in RIKEN and Kochi University of Technology respectively. He is currently a professor at the Graduate School of Computer Science and Engineering Department, Toyohashi University of Technology. He is a docent at the University of Eastern Finland in the field of Color Vision Science and Technology as from 1 November in 2017.

Reporter Profile

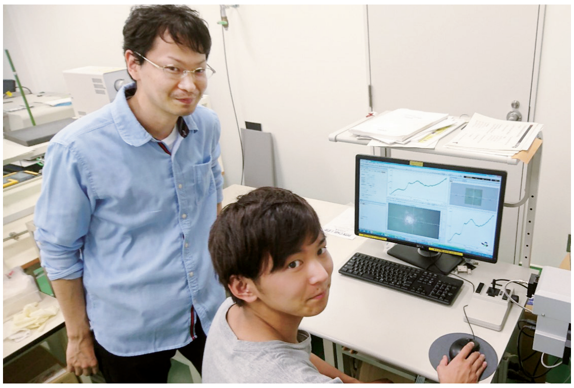
Madoka Tainaka is a freelance editor, writer and interpreter. She graduated in Law from Chuo University, Japan. She served as a chief editor of "Nature Interface" magazine, a committee for the promotion of Information and Science Technology at MEXT (Ministry of Education, Culture, Sports, Science and Technology).

Wrap an Electrode Material for Li-ion Battery into the Inner Spacing of Carbon Nanotube

Electrochemical characterization of a high capacitive electrode for lithium ion batteries using phosphorus-encapsulated carbon nanotubes

By Tomohiro Tojo

Tomohiro Tojo, Assistant Professor, and his group at the Toyohashi University of Technology have designed a unique lithium ion battery (LIB) electrode, where red phosphorus is packed into carbon nanotubes (CNTs). the new electrodes displayed reversible electrochemical reactions and maintained a relatively high structural stability of red phosphorus in the nanotubes even after the fiftieth charge–discharge cycle. The charge-discharge capacities are at least twice as high as for graphite in commercial LIBs. Therefore, it can be said that this new electrode material for LIBs with high capacity shows promise.



Assistant professor, Tomohiro Tojo (left) with his student, Kengo Aoyanagi.

In this experiment, the electrochemical performance of a new type of lithium ion batteries (LIBs) was demonstrated. These batteries are constructed using phosphorus-encapsulated carbon nanotube electrodes, whereby ultra high capacity red phosphorus is introduced into the inner spacing of carbon nanotubes (CNTs) with a tubular structure. The new electrodes indicated an improvement in the electrochemical reactivity of red phosphorus when accessible pathways of lithium ions, i.e., nanopores, were formed onto the sidewalls of the CNTs where the red phosphorus was encapsulated. Furthermore, the charge– discharge profiles and structural analysis revealed reversible electrochemical reactions as well as a relatively high structural stability of red phosphorus in the nanotubes even after the ftieth charge–discharge cycle. The charge–discharge capacity values achieved are comfortably double those achieved by graphite used in commercial LIBs. Therefore, this new electrode material appears promising for use in high capacity LIBs.

Red phosphorus has attracted attention as a higher capacitive electrode material for LIBs because it can deliver a theoretical capacity approximately seven times higher than that of the graphite currently used as a commercial electrode material for LIBs. The large difference in the capacity is thought to be due to an acceptable amount of lithium ions in the structures of graphite for LiC6 or phosphorus for Li3P. However, red phosphorus suffers enormous volumetric changes, pulverization, and peeling off during lithium ion insertion and extraction processes, resulting in rapid capacity fading due to the decrement in the amount of electrochemically reactive red phosphorus. Additionally, while electrons move onto the electrode during lithium ion insertion/extraction, red phosphorus has a disadvantage in terms of energy loss because of its low electronic conductivity.

As shown in Fig. 1 (left), Tomohiro Tojo and his colleagues at the Department of Electrical and Electronic Information Engineering, Toyohashi University of Technology, have synthesized unique structures in which red phosphorus is encapsulated into the inner spacing of CNTs to prevent its peeling off from the electrode and improve its electronic conductivity. In order to further improve the electrochemical reactivity of red phosphorus through accessible pathways of lithium ions, nanopores (<5nm) were also formed onto the sidewalls of the phosphorus-encapsulated CNTs as shown in Fig. 1 (right). After phosphorus encapsulation, Fig. 1 (left) shows that the phosphorus atoms were distributed inside the nanotubes, confirming the structural stability of red phosphorus.

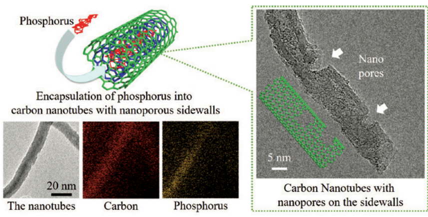


Fig.1 (left) Elemental mapping images for phosphorus-encapsulated carbon nanotubes with nanopores on the sidewalls. (right) Transmission electron image of carbon nanotube with nanopores on the sidewalls.

Using phosphorus-encapsulated CNT electrodes, a reversible capacity of approximately 850 mAh/g was achieved at the fiftieth charge–discharge cycle, as depicted in Fig. 2 (left). This was a value at least two times higher than that of graphite electrodes. Fig. 2 (right) shows the estimated ratio of charge and discharge capacities (Coulombic efficiencies) of >99% after the tenth cycle and the subsequent cycles, which indicates a high reversibility of charge–discharge reactions on red phosphorus. However, the charge–discharge capacities gradually decreased with the number of cycles because of the dissociation of some P–P bonds and other side reactions on the surface of phosphorus and the CNTs. Interestingly, the phosphorus-encapsulated CNT with nanopores facilitated a significant improvement in electrochemical performance when compared with the phosphorusencapsulated CNT without nanopores. This is suggested to be due to the high reactivity of red phosphorus with lithium ions through the nanopores on the sidewalls. After the charge–discharge cycles, red phosphorus was observed to be inside the nanotubes, as is the case shown in Fig. 1 (left).

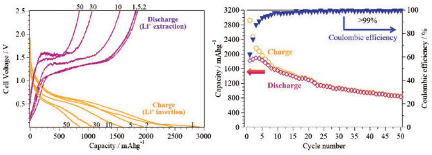


Fig.2 (left) Charge–discharge curves for phosphorus-encapsulated carbon nanotubes with nanopores on the sidewalls. (right) Charge and discharge capacities with a ratio of charge and discharge capacities at each cycle (Coulombic efficiencies).

We have proposed phosphorus-encapsulated CNTs as an electrode material for LIBs with high capacity, even though additional improvements in the structures are required to achieve long-term cycling without capacity fading. Further studies will be performed on the utilization of such electrodes.

This research was supported financially by the Murata Science Foundation, the Public Interest Tatematsu Foundation, and the Public Foundation of the Chubu Science and Technology Center.

Reference

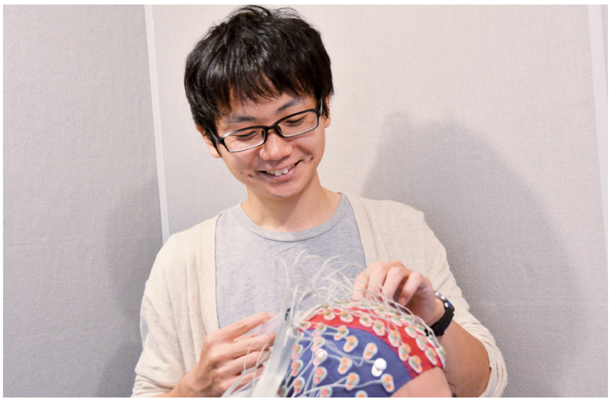
Tomohiro Tojo, Shinpei Yamaguchi, Yuki Furukawa, Kengo Aoyanagi, Kotaro Umezaki, Ryoji Inada, and Yoji Sakurai, Electrochemical Performance of Lithium Ion Battery Anode Using Phosphorus Encapsulated into Nanoporous Carbon Nanotubes. Journal of The Electrochemical Society, 165(7), A1231- 1237 (2018). https://doi.org/10.1149/2.0351807jes

Do We Subconsciously Judge Face-likeness?

Keys to uncovering the face-likeness recognition mechanism using brain waves

By Yuji Nihei

Yuji Nihiei, a Ph.D student, and a member of the research team of the Visual Perception and Cognition Laboratory at the Toyohashi University of Technology has suggested that face-likeness is judged by early visual processing at around 100ms after viewing an object. The present study focused on the relation between face-likeness recognition and brain activity to suggest for the first time that face-likeness recognition is influenced by early visual processing.
The results of the present study were published in Frontiers in Human Neuroscience.



Face-likeness recognition is the act of recognizing a non-face object as a human face. This phenomenon is called "pareidolia," and refers to "perceiving an inherently meaningless object such as a pattern, landscape or object as another object with meaning." Many spirit photographs rely on this phenomenon. While pareidolia has been argued to occur in relatively low-level visual processing, at what level of visual processing pareidolia actually occurs was never previously discerned.

Therefore, the research team of the Visual Perception and Cognition Laboratory at the Toyohashi University of Technology decided to study the relation between behavior when a face-like object is viewed and brain activity to reveal the level of visual processing at which face-likeness is recognized.

PhD student and lead author of the study Yuji Nihei explains that, "Visual processing of the human face is divided into three different stages. The first stage is early visual processing of roughly identifying the object. Then, if the object is a face, distinguishing the parts of the face (eyes, nose, mouth) from one another and processing the outline and parts of the face. Lastly, expression and individual differences are distinguished. We studied the relation between activity at these three stages of processing and the results of actual recognition and determined that face-likeness recognition occurs in the first stage of visual processing. This processing occurs at a speed of approximately 100ms after viewing an object, and so we believe that face-likeness processing occurs before we are aware of the object."

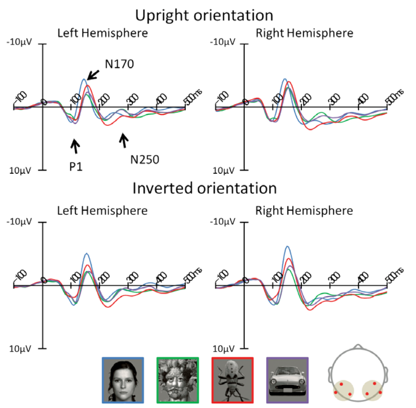


Fig.1 Brain's reaction when a face-like object is viewed

Associate Professor Minami Testuto, who leads the research team, says that, "While seeing face-likeness in various objects could be considered incorrect in terms of object recognition, we believe this is not just a mistake and actually makes us reconsider an important cognitive function. We would like to continue our study of face-likeness recognition from an objective approach."

The results of this study are believed to serve as a key to uncovering the mechanism of how humans recognize and distinguish between two types of information - "face-likeness" and objects. The results of the present study also suggest that "face-likeness" recognition occurs in early visual processing and that face-like objects are processed in the same manner as a human face in later stages. Due to this, we believe that face-likeness can be caused by an effect that gathers attention to the face, or some other like stimulus.

The present study was conducted with the assistance of Grants-in-Aid for Scientic Research numbers A(26240043) and C(25330169) from the Japan Society for the Promotion of Science. The lead writer Yuji Nihei also received a grant as part of the Program for Leading Graduate Schools (R03) run by the Japan Society for the Promotion of Science.

Reference

Nihei, Y., Minami, T., Nakauchi, S., Brain Activity Related to the Judgment of Face-Likeness: Correlation between EEG and Face-Like Evaluation, Frontiers in Human Neuroscience,
https://doi.org/10.3389/fnhum.2018.00056

Studying Insight

Does pupil dilation occur before insight?

By Yuta Suzuki

Yuta Suzuki, a Ph.D student and a member of the Computer Science and Engineering Research Team at Toyohashi University of Technology has measured the human pupil upon gaining insight into an object. It is known that pupils dilate/narrow to adjust the amount of light entering the eye and that emotional state affects the extent of dilation/narrowing. This study indicates that dilation extent varies depending on if inspiration occurs and that dilation occurs before inspiration. The results of the present study were published in Scientic Reports on May 2nd.

The Computer Science and Engineering Research Team at the Toyohashi University of Technology has measured the pupil (referred to as the "black part" of the eye) when a person is inspired by an object. It is known that the pupil dilates and narrows to adjust the amount of light entering the eye, and that the extent of dilation/narrowing varies depending on the emotional state of the person. In the present study, we measured the reaction of the pupil when a person is shown a video made to elicit inspiration (a video in which an object gradually appears). Reactions at the moment of inspiration were compared to reactions when no inspiration occurred, and it was found that the extent of pupil dilation varies depending on whether or not a person is inspired by an object and also that the pupil is already largely dilated at a previous stage. The results of the present study were published in the British scientic journal Scientic Reports on May 2nd.

As indicated by inspiration being referred to as an "aha moment" or a "Eureka moment," people perceive inspiration as a momentary event. However, a previous study reported on changes in a person's brain activity prior to them being inspired during a quiz that asked for a common word based on multiple different words. The present study investigated this further by conducting an experiment under the hypothesis that memory retrieval, which involves inspiration in object understanding, occurs in association with pupil dilation. As a result, it was found that the pupils of the experiment participants had dilated before they reported inspiration, which predicted inspiration thereafter. It is therefore believed that this discovery may lead to externally monitoring and controlling new strategies for memory retrieval in the future.

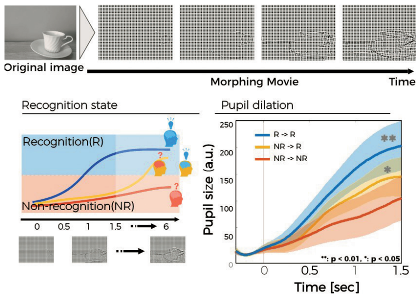


Fig.1 Example of inspiration video (top). Change in state of recognition of predicted video (bottom left). Change in pupil diameter at time of recognition (bottom right).

Lead author of the study and PhD student Yuta Suzuki explains that, "Most of the time, we are not conscious of our brain's activity. Perception and recognition are merely one part of total brain function, and there are many mysteries still left to solve with regard to this unconscious part of our brain that accounts for the majority of its activity. We decided to focus on people's object recognition and were able to use biometry to monitor the processing that occurs before a person is aware they have recognized an object. Even more surprising is the fact that a participant's condence surrounding object recognition during a recognition task did not come into play. In other words, the pupil reacted regardless of whether the participant subjectively believed they were close to getting the answer, and we only tracked whether or not they answered that they recognized the object. We believe this suggests that successful memory retrieval of an object in subconscious processing is in fact reflected in pupil dilation."

Research team leader and Associate Professor Tetsuto Minami says that, "Up until now, we mainly researched 'inspiration' by measuring brain waves, but we can now expect new developments with combinations of different measuring techniques thanks to this new discovery using non-contact pupil measurement technology."

Associate Professor Tetsuto Minami further states that, "Being inspired by objects is deeply related to memory retrieval success. If we can, for instance, uncover a brain processing mechanism in which pupil dilation and problem solving based on inspiration are related in a different way, this could be used as an index when comparing healthy patients to patients with a cerebral function disorder (for example, patients on the autism spectrum and patients with schizophrenia). Externally controlling pupil dilation is also expected to help with both diagnosis and treatment if it can be used to promote cerebral processing."

The present study was conducted with the assistance of Grants-in-Aid for Scientic Research numbers A(26240043) and B(17H01807) from the Japan Society for the Promotion of Science. The lead writer Suzuki also received a grant as part of the Program for Leading Graduate Schools run by the Japan Society for the Promotion of Science.

Reference

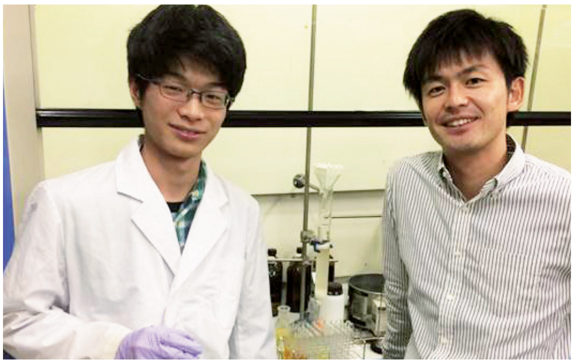
Suzuki, Y., Minami, T., & Nakauchi, S. (2018). Association between pupil dilation and implicit processing prior to object recognition via insight. Scientic Reports, 8(1), 6874.
https://doi.org/10.1038/s41598-018-25207-z

Sulfur improves birefringence!

Developing liquid crystalline molecules for high quality image displays

By Yuki Arakawa

Yuki Arakawa, Assistant Professor of Toyohashi University of Technology, and his research team, has successfully liquid crystallized π-conjugated[2] rod-like molecules with alkylthio groups containing sulfur[1], and developed high birefringence molecules that exhibit nematic liquid crystal with high fluidity in temperature ranges including room temperature. This molecular design is expected to offer a new liquid crystal material that contributes to the high quality image resolution of liquid crystal displays.



Assistant Prof. Yuki Arakawa (right) and PhD candidate.

Liquid crystal materials with high birefringence and dielectric constant have been contributing to lowering the driving-voltage and improving the response speed of liquid crystal (LC) displays. Recently, various approaches have been taken to apply high birefringence LC materials to broadband circularly polarized light-reflecting films for brightness enhancement film, or to cholestric LC lasers for continuous oscillation.

In terms of commercialization of products, LC materials need to be developed by either forming LC phases at room temperature or fixing the orientation state of LC. However, improving birefringence and dielectric constant requires both an anisotropic molecular structure and electron richness, making a rise in the phase transition temperature (especially melting point) inevitable due to large intermolecular forces. In short, it is dicult to form a liquid crystalline state under room temperature.

Assistant Professor Yuki Arakawa and his team took interest in alkylthio groups (SCmH2m+1) that contain “sulfur”, a component of hot springs and one of the few surplus resources Japan has. Although alkylthio groups have high polarizability and are expected to be an effective substitutional group for birefringence improvement, only a few successful cases of rod-like molecules with alkylthio groups forming liquid crystals have been reported due to their difficulty to crystalize.

Yuki Arakawa and his team introduced substantially long alkyl chains (having with five or more carbons to one terminal of a diphenylacetylene structure 3)) with to alkylthio groups to reveal that liquid crystallinity is exhibited during the cooling process. This is considered to be due to the fact that among the molecules aligned in an antiparallel conguration, long alkyl groups that prefer the out-of-plane conformation against the benzene ring inhibit molecular crystalline packing, and thus enable the molecules to rotate and translate while maintaining their orientation, which eventually leads to the formation of a liquid crystal phase.

Furthermore, the team observed a phenomenon where the melting point decreased due to the large bending and low electron donating properties of the alkylthio groups, and succeeded in developing a molecule that exhibits liquid crystallinity in temperature ranges including room temperature. Changing the carbon numbers in alkylthio groups after introducing long alkyl chains enables the formation of both a highly-ordered smectic phase with a high viscosity layer structure and a nematic (N) phase with low viscosity, which is particularly important for optical applications. Comparison with oxygen analogues4) conrmed significant improvement of optical properties. More recently, the team successfully developed new diphenyl-diacetylene-based π-conjugated liquid crystals with the maximum birefringence value of 0.3 or mesophases supercooled to room temperature, expanding the above mentioned molecular design.

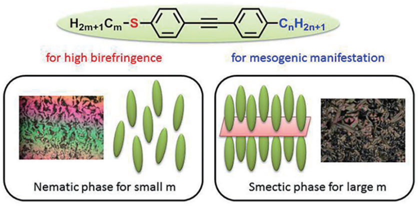


Fig.1 Images of alkylthio group rod-like molecules exhibiting liquid crystallinity at room temperature, and the phase structures.

“There were only a few reports on rod-like structure molecules with alkylthio groups exhibiting liquid crystalline phases, and no studies revealed the characteristics of these molecules, including the reason why they tend not to form liquid crystalline phases. We’re now aiming to utilize the characteristics of each phase to the full to explore various optical and electronic physical properties, including not only optical properties but also semiconductor properties,” says Assistant Professor Arakawa.

This work was partly supported by JSPS KAKENHI Grant numbers 15H06285 and 17K14493, Toyota Physical and Chemical Research Institute Scholars and research grants from the Nitto Foundation, the Toukai Foundation for Technology and Research Foundation for the Electrotechnology of Chubu.

Patent

Yuki Arakawa, Satoyoshi Inui and Hideto Tsuji. Japanese Patent Application No. (2018) 84511

Technical Terms

1) A substitutional group in which sulfur (S) and an alkyl chain (CmH2m+1) are bonded
2) A system with delocalized π electrons, created by a series of alternate single and unsaturated bonds
3) A molecular structure in which two benzene rings are connected with a triple bond
4) An analogue in which sulfur is replaced with oxygen

Reference

Yuki Arakawa, Satoyoshi Inui and Hideto Tsuji. “Novel diphenylacetylene-based room-temperature liquid crystalline molecules with alkylthio groups, and investigation of the role for terminal alkyl chains in mesogenic incidence and tendency.” Liquid Crystals, 2017.
http://dx.doi.org/10.1080/02678292.2017.1383521

カーボンナノチューブ内にリチウムイオン電池電極材料を詰め込む

リン内包カーボンナノチューブを用いた高容量リチウムイオン電池電極の電気化学特性評価

東城　友都

豊橋技術科学大学 電気・電子情報工学系 東城友都助教らの研究グループは、円筒状炭素材料であるカーボンナノチューブ(CNT)の中空孔に、高容量リチウムイオン電池(LIB)電極材料である赤リンを詰め込み、充放電試験を行いました。CNTの側壁に、10億分の1メートル(ナノメートル)の小さな孔を開けることで、リチウムイオンの出入りが容易となり、CNT内部の赤リンの反応性が向上することが示されました。50回の充放電試験を繰り返し行なっても、可逆な充放電反応を示し、赤リンはCNT内部に比較的安定に存在することが明らかとなりました。電池容量は、現行のLIB電極材料のグラファイトに比べ2倍以上となり、本研究は、高容量LIB電極材料の提案につながりま した。

赤リンをリチウムイオン電池(LIB)電極材料に用いた場合、現行のLIB電極に使用されているグラファイトに比べて約7倍の充放電容量を示す可能性があるため、赤リンは高容量LIB電極材料として注目を集めています。グラファイトの場合、6個の炭素原子が1個のリチウムイオンを吸蔵しますが、赤リンの場合、1個のリン原子が3個のリチウムイオンを吸蔵できます。このリチウムイオン吸蔵量の差から、赤リンを用いたLIBは高容量化を達成できることが考えられます。しかし、赤リンはその分、リチウムイオンの吸蔵・放出による体積変化が大きく、繰り返し充放電反応を生じると赤リン粒子の亀裂・剥離・脱落が起こります。その結果、充放電反応に寄与する赤リン粒子の量が減少してしまい、電池容量の急激な低下が問題となります。また充放電反応時に電極では電子のやり取りも生じますが、赤リンが電気を流しにくい性質(絶縁体)であるため、エネルギーロスが大きいことが問題となります。

そこで東城友都助教らの研究グループは、図1(左)に示すように、赤リン粒子の亀裂や剥離に伴う粒子脱落を抑止するために、カーボンナノチューブ(CNT)の中空孔に赤リンを詰め込んだ構造を持つ材料を合成しました。電気を流しやすいCNTは、赤リン粒子の電気的弱点を補う働きも担います。電池として充放電させる際に、リチウムイオンの移動を円滑にして、赤リンの電気化学反応性を向上させるために、図1(右)のように予めCNTの側壁にナノサイズ(<5nm)の孔を形成しても、図1(左)の分析画像からCNTの中空孔に赤リンが安定に存在することも確認できました。

この材料をLIB電極に適用することで、50回の充放電試験においても、図2(左)の通り、約850mAh/gの可逆容量が得られ、グラファイトの2倍以上の容量を示しました。また図2(右)に示す通り、10回の充放電試験以降、充放電効率(クーロン効率)は99%以上の高い値を示し、充放電反応の可逆性が高いことがわかりました。しかし、充放電を繰り返し行うと、充放電容量が徐々に低下していきました。この原因として、赤リン粒子が劣化していることや、副反応に電荷が消費されていることが考えられます。ただし、側壁に孔を開けていないCNTに赤リンを埋め込んだ電極よりも、赤リンの電気化学反応性が向上し、格段に充放電性能が向上していることが判明しました。また図1(左)と同様に、充放電後にも赤リン粒子がCNTの中空孔に存在している様子が観察され、赤リンの構造安定化を達成できました。

本研究では高容量LIB電極材料として、CNTの中空孔に赤リンを埋め込んだ構造を提案しましたが、実用時において充放電反応を長期間繰り返す場合には、更なる電極構造の改質が必要です。今後も、このような高容量LIB電極材料の研究を引き続き進めていく予定です。

本研究は公益財団法人　村田学術振興財団、公益財団法人 立松財団、公益財団法人 中部科学技術センターの支援を受けて遂行されました。

我々は無意識に顔らしさを判断している？

脳波を用いた顔らしさ認知メカニズム解明へのてがかり

二瓶　裕司

豊橋技術科学大学情報・知能工学系視覚認知情報学研究室の研究チームは、顔らしさの判断が物体を見てから約100msという早期の視覚処理で行われることを示唆しました。本研究では、顔らしさの認知と脳活動の関連に着目し、世界で初めて顔らしさ認知が早期の視覚処理の影響を受けていることを示しました。本研究成果はオープンアクセス誌frontiers in Human Neuroscienceに掲載されました。

顔らしさ認知とは、ヒトの顔ではない物体に対してヒトの顔のように認知してしまうことです。この現象は、パレイドリア現象と呼ばれ、「無意味な模様、風景、物体などが、別の意味のある何かにみえる」というものです。心霊写真の多くもこの現象とされています。この現象は、比較低次な視覚処理で生じていることは議論されていましたが、実際にどの視覚処理の段階で生じているかは明らかにされていませんでした。

そこで、豊橋技術科学大学情報・知能工学系視覚認知情報学研究室の研究チームは、顔らしい物体を見たときの行動と脳活動の関連を調査し、顔らしさ認知がどの視覚処理段階で生じるかを明らかにしました。

「ヒトの顔の視覚処理は3段階に分かれており、初めに物体の識別をおおまかに行う初期の視覚処理が行われ、顔であった場合にその顔のパーツ(目や鼻、口)の処理と輪郭とパーツの配置の処理が行われます。その後に、表情や個人の識別が行われます。我々は、この3段階の処理時の活動と実際の認知の結果の関連を調査し、顔らしさの認知が視覚処理の初期段階で既に行われていることを明らかにしました。この処理は物体を見てから約100msという早さで行われ、我々が物体を意識する前より既に顔らしさの処理が行われていることが考えられます。」と筆頭著者である博士後期課程の二瓶裕司は説明します。

研究チームのリーダーである南哲人准教授は「さまざまな物体に顔らしさを感じるというのは、物体認知としてはミスと言えますが、単なるミスではなくて重要な認知機能の裏返しではないかと考えています。今後も、顔らしさ認知について、多角的なアプローチで迫っていきたいと考えています。」

この研究の成果は「顔らしさ」という顔の情報と、物体という情報の2つの情報を持つ状態をどのようにヒトが認知し、切り分けるのかというメカニズムの解明の手がかりとなったと考えられます。また、今回の研究成果により「顔らしさ」は早期の視覚処理で行われ、その後ヒトの顔と同様に処理されていることが示されました。このことから、顔が持つ注意を集める効果等が「顔らしさ」によっても生じると考えられます。

本研究は、文部科学省・日本学術振興会科学研究費基盤研究A(26240043)、基盤研究C(25330169)の助成によって実施されたものです。また、筆頭著者の二瓶は文部科学省・日本学術振興会の実施する博士課程教育リーディングプログラム(R03)の支援を受けました。

ひらめきを科学する

ひらめきに先立って生じる瞳孔散瞳

鈴木　雄太

豊橋技術科学大学情報･知能工学系の研究チームは、ヒトが物体に対するひらめきを生じたときの瞳孔を計測しました。瞳孔は、目に入る光を調節するために、散瞳･縮瞳をする機能を持つ一方で、ヒトの精神状態を反映してその大きさが変化することが知られています。結果として、瞳孔は物体に対してひらめきを生じたかどうかでその散瞳量が変化するだけでなく、その前段階ですでに大きな散瞳を示すといった結果を見出しました。本研究成果はイギリスの科学誌　Scientific Reports に 5月2日付けで掲載されました。

豊橋技術科学大学情報･知能工学系の研究チームは、ヒトが物体に対するひらめきが生じたときの瞳孔(眼球にある、いわゆる黒目と呼ばれる部分)を計測しました。瞳孔は、目に入る光を調節するために、散瞳･縮瞳をする機能を持つ一方で、ヒトの精神状態を反映してその大きさが変化することが知られています。本研究では、ヒトがひらめきを生じさせるような動画(徐々にオブジェクトが現れる)を見ているときの瞳孔反応を 計測し、物体に対してひらめきを得たときと、得ていないときの反応を比較しました。結果として、瞳孔は物体に対してひらめきを生じたかどうかでその散瞳量が変化するだけでなく、その前段階ですでに大きな散瞳を示すといった結果を見出しました。本研究成果はイギリスの科学誌 Scientific Reportsに5月2日付けで掲載されました。

ヒトがひらめきを得る場合に主観的には一瞬の出来事のように知覚されます。これによって、ひらめきは例えば、「アハ!体験」や「Eureka moment」のように表現されます。しかしながら、過去の研究では、複数のワードからある共通のワードを想起するようなクイズにおいて、ひらめきまでの事前の脳活動の変化が報告されてきました。本研究では、これを深化させ、物体理解におけるひらめきを伴う記憶検索が瞳孔散瞳に付随して生じるのではないかといった仮説のもとで実験を行いました。結果として、瞳孔は実験参加者がひらめきを報告する前にすでに散瞳しており、その後のひらめきを予測しました。したがって、将来的にこの発見は、記憶検索のための新しい戦略を外部から観測･コントロールすることにつながるかもしれないと研究者らは考えています。

「我々の脳のほとんどは無意識に働いていて、私たちの意識に上る知覚や認知は一部であるといわれています。このため、脳処理の大部分を占める無意識の世界には未だに多くの謎が残されているといえます。我々はその中でも、ヒトの物体認知に焦点を当て、生体計測によって意識に上る前の処理を観測することに成功しました。さらに驚くべきなのは、参加者が行ったひらめきタスクにおける自信度が関連しなかったことです。つまり、参加者は主観的には、もう少しでひらめきそうだ、のような感覚に瞳孔は関連せず、ひらめきを得たと応答したかどうかのみをトラッキングしていました。これは、無意識な処理における物体に対する記憶検索の成功が確かに瞳孔散瞳に反映されていることを示していると考えています。」と筆頭著者である博士後期課程の鈴木雄太は説明します。

研究チームのリーダーである南哲人准教授は「われわれは、これまで「ひらめき」について主に脳波計測を用いて研究してきましたが、今回、非接触計測技術の瞳孔計測で発見が得られたことから、複数の計測技術の組み合わせによる新たな展開などが期待できます」と説明します。

続けて、南哲人准教授はこう主張します。「物体に対するひらめきは、記憶検索の成功と深い関連があり、例えば、瞳孔散瞳とひらめきに基づいた問題解決との間の関連が異なる脳処理メカニズムを見出すことができれば、健康な参加者と脳機能に問題を抱えている患者(自閉スペクトラム症や統合失調症等)との比較に使用するための指標になりうるのではないかと考えています。また、瞳孔散瞳を外部からコントロールすることによって、そういった脳処理を促進することができれば、病気の診断だけではなく、治療に役立っていくのではないかと期待しています。」

本研究は、文部科学省・日本学術振興会科学研究費基盤研究A(26240043)、基盤研究B(17H01807)、の助成によって実施されたものです。また、筆頭著者の鈴木は文部科学省･日本学術振興会の実施する博士課程教育リーディングプログラムの支援を受けました。

硫黄を導入したπ共役系棒状液晶分子の開発

荒川　優樹

豊橋技術科学大学の荒川優樹助教らは、硫黄成分を有するアルキルチオ基[注1)]を導入したπ-共役系[注2)]棒状分子の液晶化に成功し、室温を含む温度範囲で流動性の高いネマチック液晶を示す高複屈折性分子を開発しました。この分子設計により、液晶ディスプレイの高画質化などに寄与する新しい液晶材料としての応用が期待されます。

複屈折や誘電率(異方性)の大きな液晶材料は、主に液晶ディスプレイの低駆動電圧化、応答速度の向上などに寄与しております。さらには近年、様々なアプローチにより高複屈折性液晶材料は、輝度向上フィルムなどに用いられる広帯域円偏光反射フィルムや、連続発振を目指すコレステリック液晶レーザーに使われるなど、その応用例は増えております。

液晶材料を開発する上で実用性を考えると、室温で液晶相を形成するか、液晶の配向状態を固定する必要があります。しかしながら、複屈折や誘電率の向上には異方的な分子構造を有し、かつ電子リッチであることが必要条件であるため、大きな分子間力による相転移温度(特に融点)の向上は避けられません。つまり、室温では液晶状態を形成しにくくなります。

荒川優樹助教らは、温泉などの成分にも含まれ、日本の数少ない余剰資源である「硫黄」を含むアルキルチオ基(SCmH2m+1)を導入した分子系における液晶材料の研究を行ってきました。アルキルチオ基は分極率が高く、複屈折の向上に有効な置換基であることが期待されますが、一方で、アルキルチオ基を導入した棒状分子は液晶性を形成しにくく、π—共役系棒状分子において液晶性を示した報告例はほとんどありません。

これまでに、図1に示す、アルキルチオ基を導入したジフェニル-アセチレン構造(三重結合数が1)[注3)]の、片末端に炭素数5以上の十分な長さのアルキル鎖を導入することで、冷却過程において液晶性が発現され、さらには一部の誘導体は室温以下までその液晶相が過冷却されることを明らかにしました。これは、反平行に配列した分子間において、ベンゼン環の面外方向に安定なコンフォメーションを有するアルキル基(CnH2n+1)によりその分子間のパッキングが緩和され、配向を維持したまま分子の回転および併進運動(分子の位置の融解)が可能となることで液晶相が形成され、アルキルチオ基の大きな屈曲や低い電子供与性により転移温度が低温化するものと考えられます。また、長いアルキル基を導入した上で、アルキルチオ基の炭素数を変えることにより、粘性の高いレイヤー構造を有する高次のスメクチック相から、特に光学用途に重要な粘性の低いネマチック(N)相の形成までを作り分けることが可能となります。これらは、酸素類縁体[注4)]との比較でも光学特性が大幅に向上していることも確認されました。また最近では、上記分子設計指針を基に、三重結合を一つ拡張したジフェニル-ジアセチレン構造(n=2)における室温液晶、ならびに複屈折が最高で0.3に到達する高複屈折性液晶材料の開発にも成功しております。

「棒状構造の分子にアルキルチオ基を導入した液晶分子の報告例は極めて少なく、なぜ液晶相を形成しにくいのか、その原因も含めて、それら分子の特徴を明らかにした研究例はありませんでした。今後はそれぞれの相の特徴を最大限に生かし、光学特性だけでなく、半導体特性など、様々な光･電子物性の開拓も目指して参ります。」と荒川助教は述べています。

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用語解説

注1) 硫黄に(S)にアルキル鎖(CmH2m+1)が結合した置換基

注2) 単結合と不飽和結合が交互に連結し、π電子が非局在化した系

注3) 二つのベンゼン環が三重結合で連結した分子構造

注4) 硫黄が酸素に置き換わった類縁体

Pick Up

TUT's state-of-the-art technological innovation at "Innovation Japan 2018" in Tokyo

"Innovation Japan" is the largest event in Japan which brings industry together with technological innovators from Japanese universities. It is hosted by the Japan Science and Technology Agency (JST) and the New Energy and Industry Technology Development Organization (NEDO).

The annual "Innovation Japan" event, now in its 15th year, was held at Tokyo Big Sight on August 30th-31st 2018, with 400 technological innovators and 58 university organization exhibitions.

TUT exhibited the following technology at the event this year.

TUT exhibitions at "Innovation Japan 2018"
State-of-the-art technological innovation exhibition
• Development of air-pressure control atmos furnace for rapid synthesis and Red phosphor with high-purity color (Hiromi Nakano) • High resolution multichromatic illuminator for next generation optogenetics (Yuu Hirose) • The mass production of iPS cells by the Water-in-oil Droplet electroporation (Rika Numano) • A GaN integrated electronics for high performance devices operated under harsh environment (Hiroshi Okada)
University organization exhibition
Exhibition theme: "Creation of a smart symbiosis society with robots" • Cutting-edge research results on sensing and brain information were presented. • Social implementation of industrial robots jointly developed with enterprise were demonstrated.

TUT Promotion Video is now available

You can check out the new TUT promotion video on YouTube's "Toyohashi University of Technology" channel.

- https://www.youtube.com/channel/UC2gapYsJ8gTNiM6cJ14N37Q

TUT Research

e-Newsletter from Toyohashi University of Technology

https://www.tut.ac.jp/english/newsletter/

Toyohashi University of Technology

The Toyohashi University of Technology (TUT) is one of Japan's most innovative and dynamic science and technology based academic institutes. TUT Research is published to update readers on research at the university.

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