



Title	Body Ownership Transfer to BCI-teleoperated Android Robots : An Investigation of Mechanism and Effects
Author(s)	Alimardani, Maryam
Citation	大阪大学, 2015, 博士論文
Version Type	
URL	https://hdl.handle.net/11094/52073
rights	
Note	やむを得ない事由があると学位審査研究科が承認したため、全文に代えてその内容の要約を公開しています。全文のご利用をご希望の場合は、大阪大学の博士論文についてをご参照ください。

The University of Osaka Institutional Knowledge Archive : OUKA

<https://ir.library.osaka-u.ac.jp/>

The University of Osaka

Abstract of Thesis

Name (Maryam Alimardani)	
Title	Body Ownership Transfer to BCI-teleoperated Android Robots: An Investigation of Mechanism and Effects (ブレイン・マシン・インターフェースによるアンドロイド遠隔操作時の身体感覚転移: そのメカニズムと影響に関する研究)
Abstract of Thesis The illusion of body ownership transfer (BOT) to human-like android robots is a sensation of embodiment into robot's body that operators report during the teleoperation of robot's motions. It is a recently discovered phenomenon that has shown potentials for understanding the fundamental aspects of our perception of own body and self. The aim of this research was to investigate about the underlying mechanism of such BOT illusion and its effects on the operators. Using a brain computer interface (BCI), we developed an experimental tool with which we could inspect the cognitive model and consequent effects of such illusion in human brains. Four experiments, designed to address the cognitive underpinnings and effects of BOT, are presented. In Experiment 1, we confirmed the inducement of body ownership illusion for a pair of BCI-teleoperated robot's hands by translating subject's imagination of a grasp movement into robot's motions of grasp. Using BCI system and removing bodily movements during operation, we could clarify the role of proprioceptive feedback in the earlier introduced cognitive model of self-attribution during voluntary movements. In the previous works, the illusions of ownership were mainly induced by integration of multiple sensory feedback channels. However for the first time we could show that even without integration of proprioceptive feedback, the synchronization between one's motor intention and one sensory channel that was visual feedback of planned motion could result into a sense of agency and ownership for the seen motions and body. In addition, results showed that the strength of illusion was linearly correlated with the subject's BCI performance. In Experiment 2, we further investigated the contribution of proprioception in the inducement of body ownership illusion under the inevitable delay of real time operational system. To that end, we compared the intensity of BOT illusion when the subjects controlled robot's hands either by motor imagery (BCI-teleoperation without real body movements) or by motor action (previous motion-capture system tracking real body movements). The results indicated that under delayed visual feedback, the removal of mismatching sensory signals such as proprioceptive feedback in a high-performance BCI-teleoperation could enhance the sense of agency and illusion of ownership. From above two experiments we realized two facts: First the practicality of BCI systems in the inducement of BOT illusion for teleoperated androids (Experiment 1 and 2), and second the correlation between subject's operational skills and the intensity of illusion (Experiment 2). In the following two works, we were further interested in the effects of body ownership illusion on the operators of a BCI-controlled android. Therefore we challenge the employment of BOT illusion in the BCI feedback design in order to improve subjects' BCI performance and motor imagery skills.	

In **Experiment 3**, we positively and negatively biased the performance of subjects in the presented visual feedback to manipulate the strength of BOT illusion and evaluated changes in the subject's real performance. Although subject's online performance did not show any changes due to feedback bias, offline classification of brain activities demonstrated a more discriminant feature distribution during motor imagery tasks in the positively biased session. This result suggest that when the subjects received an enhanced feedback of their performance during robot's hand operation, the feeling of being the cause of the motions and the controller of the hands assist them modulate their brain activities toward an improved motor imagery pattern.

In **Experiment 4**, we focused on measuring the direct contribution of BOT illusion to the improvement of subject's motor imagery skills by changing the robot's appearance in the visual feedback. Two groups of subjects teleoperated a different robot: a pair of very human-like android hands versus a pair of robotic gripper. The results did not show any significant change in the trend of learning probably because the robotic gripper was to some extent similar to human hands and subjects' assessment of BOT illusion was unexpectedly high. However in the follow up session, when both groups repeated BCI-teleoperation with the robotic gripper, the group who initially practiced the task with android hands showed significantly higher controlling skills than the other group who only experienced the operation of robotic gripper. This shows that motor imagery skills learnt during the BCI-operation of humanlike hands are robust to time and visual feedback changes. Future experiments with a completely non-humanlike robot are required to rechallenge the comparison of motor imagery learning due to BOT intensity and feedback human-likeness.

All together, by suggesting a positive interaction between the inducement of BOT illusion and improvement of subjects' operational skills, our findings reveal the promising nature of BCI-teleoperation for an efficient interaction through android robots and furthermore the application of such system in the future BCI training paradigms.

論文審査の結果の要旨及び担当者

氏 名 (Maryam Alimardani)			
論文審査担当者	(職)	氏 名	
	主 査	教 授	石 黒 浩
	副 査	教 授	西 田 正 吾
	副 査	教 授	細 田 耕

論文審査の結果の要旨

本論文では、アンドロイド（人のような外見をもつロボット）を遠隔操作する際に見られる、「身体感覚転移」の現象について研究を行ってきました。これは、アンドロイドを操作しているときに、触覚がアンドロイドから伝えられていなくても、アンドロイドが触られると自身が触られたような気がする、つまりアンドロイドを自己の身体の一部と錯覚する現象です。従来の研究によって、この錯覚が単なる気のせいではなく、生理指標でも反応が生じることなどがわかっていました。しかし、本論文ではさらに研究を進め、アンドロイドにブレイン・マシン・インタフェースを組み合わせることで、脳内過程のモデルを構築するとともに、モデルに基づき、アンドロイドの遠隔操作を脳波信号で行うことで、触覚や固有感覚（身体姿勢、位置などの感覚）を排除した場合であっても、運動意図があり、運動の結果を見るだけで、アンドロイドを自分の身体の一部のように感じられることを明らかにしました。この得られた結果は、先端的なデバイスを効果的に用いた巧妙な実験設計によって成し遂げられたものであり、人の認知機構や発達過程を理解する上でも重要な成果といえます。

さらに、上述の実験過程で得られた知見から、アンドロイドのブレイン・マシン・インタフェースによる操作時に、フィードバックの与え方を変えることで、操作者の脳波の空間的なパターンを変えることができることも発見しました。一般のブレイン・マシン・インタフェースによる操作は、完全なパフォーマンス（正答率）を得ることは難しく、誤判定による操作エラーが問題となりますが、この研究では、アンドロイド操作時のフィードバックの与え方を変えるだけで、操作者の脳波の分布パターンが変わり、識別エラーを大幅に減らすことができることを示しています。これは近年注目されているニューロフィードバック（被験者に脳波の状態を見せることで、脳波の発生パターンを自ら変更しようとするもの；発達障害などの治療法として期待されている）の新しい手法として注目される成果であるとともに、近年活発に研究されているブレイン・マシン・インタフェースの性能を大幅に向上できる可能性があります。

以上のように、本論文の成果は、先端的なアンドロイドやブレイン・マシン・インタフェースを使いこなし、従来知見の綿密なサーベイとしっかりとしたモデル化に基づいて行われた点も含め、高い独創性を有しているので、博士（工学）の学位論文として価値のあるものと認めます。