# Alien hand syndrome: a neurological disorder of will

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## Summary

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Alien hand syndrome (AHS) is a neurological disorder in which movements are performed without awareness or conscious will. Phenomena like awareness or consciousness are still poorly studied in physiology and have only become a crucial topic in neuroscience in the last few years. Pertinent experiments in which the volitional control of a movement was studied unanimously, demonstrate that movements are initiated before consciousness occurs. By doing so, the brain adopts internal anticipatory models of voluntary action. Several studies suggest that the parietal cortex is important in activating and maintaining such internal models of action. AHS is characterized by a loss of the sense of agency associated with the purposeful movement of the limb while retaining a sense of ownership. The hand seems to perform acts without intentional guidance by the patient. Thus, the patient has no control over the movements; instead, the hand has the capability of acting autonomously, independent of patient's voluntary control. This complex phenomenon may present in different variants which are caused by different lesions and can be categorized by several dimensions:

– type of aberrant behavior performed by the affected hand;
– coordinative disturbances in a bimanual behavior, caused by conflicts arising while using both hands;
– subjective reactions of the affected individual toward this limb.

The syndrome and its variants is caused by lesions to the medial frontal lobe, the corpus callosum and the parietal areas, but can also appear within neurodegenerative diseases, such as corticobasal degeneration, and may even precede them (e.g. Creutzfeldt-Jakob disease). In a functional MRI study of AHS, major activation was reported for the frontal inferior gyrus of the dominant hemisphere in voluntary movement of the affected hand, suggesting an important role of this area in organizing willed actions. Neuropsychological investigations indicate an involvement of a supramodal attentional system in the organization of movements. AHS serves as a paradigm to study the conscious experience of movement and can be considered as a neurological disorder of will. This review discusses some physiological as well as functional-neuroanatomical aspects, by reporting some actual studies relating AHS to consciousness and will.

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## Introduction

Alien hand syndrome (AHS) is a neurological disorder in which movement is performed without awareness or conscious will. The phenomena of awareness or consciousness is still poorly studied in physiology and has only become a crucial topic for neuroscience in the last few years [1]. There are two principal theories about consciousness. While dualistic views think that the brain and mind are separate entities, the monistic perspective supports the idea that there is only one ultimate substance or principle governing our mind, assuming the latter to be a product of the brain. In this second view, consciousness is composed of different perceptions and feelings; for example the sound of a symphony, the perception of the color of a flower, the feeling of love or anger, the decision to make a movement. All these feelings and experiences may vary widely and, in each of these cases, the mental state of the subject bears a very distinctive subjective character. There is something that it is *like* for the subject to undergo each state, some phenomenology that it has. In philosophy, the term 'qualia' (singular 'quale') is used to refer to the introspectively accessible, phenomenal aspects of our mental lives, hence describing the subjective quality of conscious experience [2]. Though it is difficult to deny that there are qualia, it is still debateable which mental states they have, whether qualia are intrinsic qualities of their bearers, and how qualia relate to the inner and outer physical world. Nevertheless, the concept of qualia is central for the understanding of the nature of consciousness and the mind-body-problem in general. In the specific field of willed action, the principal question is "When and where in the brain does the conscious experience of a movement occur?"

## Functional anatomy of the motor system

To have a better understanding of the volitional control of a movement, it is important to remember the human motor pathways. In a voluntary movement (e.g. gesturing, grasping, talking, walking), the primary motor cortex, inferior frontal gyrus, dorsolateral prefrontal cortex, anterior cingulate, supplementary motor area (SMA), pre-SMA and other frontal mesial, parietal, and limbic areas are all involved. The anatomical sites involved in motor performance and imagination have been intensely studied by functional imaging methods (e.g. [3]). Even simple movements like pressing a key on a keyboard to type a letter can be regarded as a complex motor task to be performed by

the brain (e.g. to select which muscles to activate, to estimate the force needed etc.), involving cortical as well as subcortical motor loops. The primary motor cortex (Brodmann Area 4, or M1) is one of the principal brain areas involved in motor function. This area lies anterior to the central sulcus and generates neural impulses that control the execution of movement. Other (secondary) regions of the cortex involved in motor control include the premotor cortex (lateral region of Brodmann Area 6) and the SMA (medial region of Brodmann Area 6). Regions of the posterior parietal cortex are involved in the planning and control of actions (e.g. transforming visual information into motor commands). This is accomplished by sending this information to the premotor cortex and the SMA. There have been other regions identified along the intraparietal sulcus which are associated with eye, arm, leg and hand movements, as well [4]. The premotor cortex is involved in the sensory guidance of movement. It controls the more proximal muscles and trunk muscles of the body. The SMA is involved in the planning of complex movements and in bimanual coordination. Both, the SMA and the premotor regions, send information to the primary motor cortex as well as to brainstem motor regions. Fibres originating in M1, SMA and the premotor cortex constitute the corticospinal tract, which is the only direct pathway from the cortex to the spine where they travel through the brainstem; most of them decussate contralaterally and then descend through the spine, to terminate at different levels. The corticospinal tract represents one of the latest evolutionary adaptations, appearing only in mammals. In humans, the corticospinal tract is the main pathway for control of voluntary movement. It represents a means over which the cerebral hemispheres can phylogenetically control older motor structures. Other motor pathways, originating from the subcortical nuclei are involved in the control of posture and balance, as well as in the coordination of coarse movements of the proximal muscles, head, neck and eye in response to visual targets. Subcortical pathways can modify voluntary movement through interneuronal circuits in the spine and through projections to cortical motor regions. The basal ganglia and the cerebellum constitute the two most prominent subcortical components of the motor pathway. The cerebellum is especially involved in the timing and coordination of motor programs, while the actual motor programs are generated in the basal ganglia. The basal ganglia consist of five nuclei and the input is mainly restricted to the two nuclei forming the striatum (caudate and putamen), whereas the output is almost exclusively channelled via the internal segment of the globus pallidus, together with parts of the substantia nigra.

Taken together, to transform an action goal into purposeful movement, the motor cortex and brainstem structures need the assistance of both the basal ganglia and the cerebellum. Hence, all of these components form a hierarchy with multiple levels of control, since several cortical and subcortical regions are involved in organizing motor programs for complex movements. Moreover, since the same pathways are also involved in both perceptual as well as motor skills, it becomes evident that damage to these regions may result in inappropriate perception as well as inproper guidance of spontaneous movements.

## Consciousness and movement: insights from neurophysiology

Pertinent neurophysiological studies provide evidence that the brain initiates a movement before the action is consciously experienced. One of the most seminal experiments was done by Libet and coworkers [5]. In this study, the subjects were asked to perform a simple voluntary movement. While performing this task, the participants were instructed to focus their attention on either the actual onset of the movement or the internal decision to execute it. The M-judgment was the time they made the movement and the W-judgment was the time they first became aware of their intention to move. The results obtained by Libet and colleagues were somewhat unexpected. As hypothesized, the W-judgment occurred about 200 ms before the EMG onset while the M-judgment occurred about 90 ms prior to EMG onset. The onset of the Readiness-Potential (RP), or *Bereitschaftspotential* (it depends on the activation of SMA), instead, began 850 ms prior to the W-judgement. These results led the authors to conclude that movements are initiated before conscious experience occurs. In another study by Haggard and Eimer [6], the authors recorded the lateralized Readiness Potential (LRP) in order to obtain a more specific marker of motor preparation, since the LRP is thought to reflect the time-point when lateralization of the response occurs. Consistent with the Libet data, the average LRP occurred about 800 ms before movement onset. Moreover, they could show that LRPs latencies were significantly shorter for early W-Judgments than for late W-judgments which was not the case for RPs. This additional observation led the authors to conclude that conscious intention to initiate a movement arises after a preparatory stage (RP). The time difference of about 200–300 ms between W-judgment and motor action suggests that an intended movement is processed after the time of conscious intention. There is evidence that the SMA and pre-SMA are the candidate regions where LRPs do originate [7]. Moreover, activation in the SMA can be found, when attending to the time of a conscious intention to move [8]. Hence, taking into consideration the aforementioned experiments, it seems justified to speculate that these regions play a major role in the mediation of conscious and volitional intention (to move). This assumption has been further corroborated by stimulation studies in patients with epilepsy [9] showing that direct electrocortical stimulation of the SMA triggered intentions of precise movements, but leaving the patients as if they were not the agents of their movements. Moreover, augmentation of stimulation intensity caused the evoked movements to occur. Based on data from high resolution EEG and fMRI experiments, Ball and coworkers [10] hypothesized that the release of the motor command is triggered by the SMA by suppression of inhibition exerted on the primary motor cortex.

## The role of the parietal lobes

There is clinical as well as experimental evidence linking the feeling of intentionality to the posterior parietal cortex (PPC). Patients with parietal damage are not capable

of predicting the time necessary to perform various hand movements, indicating the involvement of this region in conscious motor images. The Libet experiment was adapted by Sirigu and coworkers in patients with parietal lesions [11]. Normal subjects were accurate when estimating movement onset and they were in advance when estimating the time they first intended to move. Patients with parietal lesions also made accurate M-judgment, but, in striking contrast with normal individuals, they reported the W-judgment very close to that of movement onset. Speculating about this short delay, the authors concluded that the parietal damaged subjects could not rely on the early activity of the posterior parietal areas to be aware of their intention to move, but instead, depended on the release of the motor command triggered by the SMA. This hypothesis is again substantiated by electrocortical stimulation studies in conscious patients undergoing tumor removal [12]. In fact, electrocortical stimulation of the parietal cortex (BA 39, 40) was followed by an explicit intention to move the limb. In contrast to the aforementioned SMA-stimulation experiments, PPC-stimulations were less specific concerning the precise movement and an increase in stimulation intensity was not able to elicit motor responses.

Considered together, it can be summarized that, initial, unconscious intentions to act, arise in a prefrontal-parietal network, causing a subsequent nonspecific activation of the precentral motor system. Further downstream, conscious intention to move occurs as activation within the posterior parietal area increases. Finally, the SMA inhibits suppression on M1 for the motor command to be transformed into a movement, causing a conscious, intentional urge to move.

**Table 1**
Terms and clinical signs in Alien Hand Syndrome (adapted from [14]).

| Term | Definition |
|---|---|
| Alien hand syndrome / Alien hand sign | Foreign or uncooperative behavior of a hand. This term is used today as the name for the syndrome with all of its components. |
| Posterior alien hand | The alien hand syndrome that may follow posterior lesions, characterized by hand levitation and abnormal postures. |
| **Type of aberrant motor behavior of the alien hand** | |
| Magnetic apraxia / repellent apraxia | Instinctive grasping/avoiding with an abnormal posture. |
| Compulsive manipulation of tools | Manipulating objects by the abnormal hand against the patient's own will. This term is used mainly in the Japanese literature. |
| Anarchic hand | Autonomous behavior of a limb without the denial of ownership. |
| **Subjective** | |
| Stranger's hand sign | Denial of ownership of a limb. |
| Strange hand sign | The original meaning of the alien hand sign (la main étrangère). Failure to recognize the abnormal hand as one's own hand. |
| Autocriticism, interhemispheric autocriticism | Expression of astonishment with the behavior of the abnormal hand. |
| **Interhand interaction** | |
| Diagonistic dyspraxia | A conflict between the desired act and the performed act. |
| Intermanual conflict | The hands act at cross-purposes to each other. |
| Agonistic dyspraxia | Compulsive automatic execution of orders by one of the hands when the patient is asked to perform the movement with the other hand. |

## Clinical aspects of alien hand syndrome

AHS is a rare neurological disorder characterized by a loss of the sense of agency associated with the purposeful movement of the limb while retaining a sense of ownership. The patient has no control over the movements, instead, the hand has the capability of acting autonomously, independent of their voluntary control. The affected hand can perform complex acts. In one of the first clinical papers, the authors [13] coined the term "main etrangère" when describing the puzzling behavior of some patients who failed to recognize their own left hand when deprived of visual feedback after callosotomy.

This complex phenomenon may present in different variants which are caused by different lesions. According to Biran and Chatterjee [14], the phenomenon of AHS can be categorized as

a) coordinative disturbances in bimanual behavior caused by conflicts arising while using both hands (e.g. *intermanual conflict* [hands acting at cross-purposes to each other], *diagonistic behavior* [conflict between desired and performed act] or *agonistic apraxia* [automatic execution of orders by one hand while using the other hand]),

b) purposefulness of movements (e.g. compulsive manipulation of tools [manipulating objects by the abnormal hand against their own will, sometimes referred to as "anarchic hand" [15], autonomous behavior of the hand without the denial of ownership, or magnetic/repellent apraxia [instinctive grasping / avoidance hand movements]

c) subjective reactions of the affected subject toward this limb (e.g. interhemispheric autocriticism [overt astonishment caused by the behavior of the abnormal hand], or stranger's hand sign [denial of ownership of the hand]).

The patient is conscious of the deficit and usually the deficit is not associated with apraxia. The deficit can fluctuate and often depends on attentional and emotional status of the patient. There is a tendency of perseveration and often the movements are driven by objects in the peripersonal space of the patients. Many patients have an intermanual conflict.

## AHS and will

Patients with AHS are usual affected by a pathology involving specific regions of the brain. The areas mainly affected are the medial frontal lobe, the corpus callosum and the parietal areas [16, 17].

There are only few cases in which the authors attempted to describe the relationship between AHS and will [17, 18].

In the study by Assal et al. [17], they report a patient with a right parietal lesion with an AHS. The authors conducted a functional MRI and studied the areas involved during involuntary and voluntary movements of the affected left hand. The voluntary movements activated more areas than the involuntary movements, particularly in the frontal inferior gyrus of the dominant hemisphere, suggesting an important role of this area in organizing willed actions. Thus, while planned movements originated in the frontal lobe before being sent to the motor cortex, the alien hand move-

ments showed no activity in the frontal lobe but activated the contralateral primary motor cortex, as if they originated from the motor strip itself. Moreover, the activation was restricted to the motor strip without backchannel to the frontal lobe, leaving the patient unaware of his own movements. Considered together, the authors found that alien hand movements were associated with highly selective and isolated contralateral M1 activation while voluntary movements involved an extensive bilateral distributed network extending beyond the primary motor cortex, including frontal gyrus and dorsolateral prefrontal cortex. They concluded that the neural activity restricted to M1 may arise during unwilled or unconscious motor action, thus providing a direct demonstration that human motor pathways can function in the absence of motor awareness [17].

Another point in case was evidenced in the study performed by Giovannetti et al. [18] by adopting an extensive neuropsychological evaluation. To challenge the view that a) alien hand movements are triggered opportunistically by nearby objects and that b) alien hand behaviours are increased in conditions of fatigue or anxiety (i.e. under reduced attentional control), the authors tested these predictions with a 56-year-old patient with AHS, due to a stroke leading to a left medial frontal lesion, in two experiments using a realistic coffee making task. Experiment 1 (CC = preparing coffee under time pressure including the presence of multiple functionally and visually similar distractor objects) demonstrated that the affected hand was highly persistent and strongly influenced by exogenous but not endogenous factors while the nonalien hand made fewer errors. In experiment 2 (oral trail making test (OTMT) as the concurrent task to the CC), the authors noted a disproportionate increase in perseverations and exogenous errors of the affected hand under the secondary task load. The nonalien hand was significantly less disrupted by dual task conditions. The authors use their data to provide experimental support for previous anecdotal observations about alien hand behaviours in natural settings, speaking in favour of an unilateral defect in endogenous control.

## Conclusions

In this short review, we report some data from the literature regarding AHS and willed action. AHS is characterized by a limb that seems to perform meaningful acts without being guided by the intention of the patient. Several studies with patients affected by this syndrome have been discussed which speak in favor of parallel involvement of different anatomical networks including the frontomesial lobe, the anterior cingulate, the parietal areas and the premotor areas. AHS can be regarded as a disorder of will. Patients find themselves unable to stop the alien limb from reaching and grabbing objects, and they may be unable to release these grasped objects without using their other hand to suppress the unintended movements. Moreover, the affected individuals frequently express astonishment and frustration at the errant limb and they may even castigate the limb for behaving in a peculiar way. Since the patients experience the alien hand movements as being controlled by an external agent, the question arises regarding which brain structures are necessary for movements to be interpreted as "willed actions". There is accumulating evidence speaking in favour of the PPC to be a candidate structure.

This contribution has outlined the terminology used in describing this syndrome, has described some seminal observations and has outlined some aspects regarding its functional neuroanatomy.

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