Research report

The top down and bottom up mechanisms involved in the sudden awareness of low level sensorimotor behavior

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Abstract

Motor control can be achieved in the absence of awareness, even when performed intentionally. The aim of this study was to understand the mechanisms of the sudden awareness of our own movement. This was studied in locomotion because it is an automatic behavior which can be intentionally modulated. Subjects walked continuously with the instruction to maintain either a constant walking speed (compensation condition) or constant propulsive forces (no-intervention condition); they were sometimes faced with slow variations in resistance that they had to detect. The results show that: (1) the subject remains unaware of his force increase (in compensation) or his walking velocity decrease (in no-intervention) for a long time, although these modifications go largely beyond the variability range in which he is able to intentionally control his force (in no-intervention) or his velocity (in compensation) and (2) the detection of the resistance increase occurs at the same time in both conditions. We conclude that the sudden awareness of a movement pattern produced at a low level was found to emerge from the interaction between a top down mechanism where the intentional control of goal feedback delays the aware perception of the other sensory sources and a bottom up mechanism where high level mechanisms of sensorimotor integration come into play beyond a discrepancy threshold between different sensory information. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

It is from the distinction between a high level controlled processing and a low level automatic processing that the notion of consciousness appears in cognitive psychology. Many studies have demonstrated that during our own actions, motor control can be achieved in the absence of awareness, even when performed intentionally [5,7]. For example, by giving false visual feedback about the trajectory of the hand movement, Fourneret and Jeannerod [5] demonstrated that the subjects, who cannot see their hand, were able to voluntarily achieve the desired result of drawing a straight line on a computer screen by making deviant movements but they were not aware of this deviation. As emphasized by Woodworth [11] ‘In voluntary movement, the intention is related to the goal of action and not to the means of movement production. The movement follows from the mind of the result of action and not from the mind of movement’ [11]. However, in these experiments, one can suspect that if the discrepancy between the feedback about the knowledge of result and the proprioceptive feedback from the movement would increase, the subjects would become suddenly aware of their deviant movement. The aim of this study was to understand the influence of top down mechanisms linked to conscious goal of action and bottom up mechanisms linked to sensory discrepancy in the sudden awareness of our own movement. This allows understanding of the on-line dialog between a high level controlled processing and a low level automatic processing in motor control.

Locomotion is particularly well-suited to the aim of this study because it is an automatic behavior which can be
intentionally modulated [8,10], therefore the intentional processes can be clearly separated from the automatic bases. When we are walking through space, our intention is to move from one point to another in a certain period of time. Although we are conscious of the spatial goal, we are generally not aware of our leg movement which is controlled at a spinal level by the Central Pattern Generators [3]. When studying treadmill walking, the displacement through space and its related visual information is removed. So, if the subject wants to control his displacement, he needs to focus on his leg-somatosensory feedback—the kinetic inputs coming from the generation of propulsive forces [4] or the kinematic inputs coming from rhythmic leg movement, via muscle-spicules, and joint receptors [9].

In the absence of external forces, the walking velocity covaries with propulsive forces. But, if the external forces increase, the kinematic and kinetic feedback are dissociated. So, if subjects are required to walk while voluntarily maintaining their walking velocity despite increasing external forces, they will voluntarily produce the same leg movement kinematics (goal feedback) but the propulsive forces will progressively increase (sensory consequences). Inversely, if subjects are required to maintain the same propulsive forces (goal feedback), the stride length and frequency will decrease because of the increase in external forces (sensory consequences). In the present experiment, subjects walked continuously with one or the other of these two instructions (constant walking speed or constant propulsive forces); they were sometimes faced with slow variations in resistance that they had to detect as a double task. To study the influence of top down mechanisms linked to conscious goal of action in the sudden awareness of leg movement production (organized at low level), we compared the thresholds of awareness of the modification of sensory afferents when these afferents (kinetic or kinematic) are and are not linked to the conscious goal. Finally, to know if the bottom up mechanisms involved in the sudden awareness of movement depend on the modified sensory input, the sudden awareness of the propulsive force increase was compared with the sudden awareness of stride parameters decrease (amplitude and stride frequency).

2. Materials and methods

After having given their informed consent, six volunteer young adults (two men and four women) participated in this experiment. All subjects were familiar with walking on the treadmill.

Subjects walked on a treadmill driven by their own locomotor activity (Gymroll Sprint 1800, 0–8 km/h, walking surface 0.6 m wide and 1.80 m long, with lateral protective bars). The treadmill motor was a torque servomotor. The torque was controlled by a computer, that allowed, in some conditions, to modify the resistance of forward displacement by modifying the support inertia. This set-up left subjects entirely free to adopt the walking speed that they wished (for more details see Ref. [2]).

During a 1 h training session, the subjects familiarized themselves with the task in each condition. Variations of resistance were delivered in blocks. Each block lasted about 10 min and was composed of the same basic pattern repeated 20 times. This pattern consisted of a steady walking period of 10 to 20 s (the duration of period was randomized in order to avoid all anticipation) during which the initial resistance $R_0$ was constant, followed by a period during which the resistance increased linearly for 10 s until a resistance $R_1$ before returning to the $R_0$ value after 5 s. The resistance $R_0$ can be considered as a normal external force, since the power required to accelerate the center of mass in the forward direction at each step was the same as in usual overground walking. The $R_1$ value was chosen to result in a substantial increase in the traction power (about 60%) for walking at the same speed (which could be easily performed by healthy people). Values for $R_0$ and $R_1$ were made proportional to the subject’s body mass. To avoid fatigue, subjects rested for 5 min between blocks. The experiment was divided into two sessions of two blocks, one for each experimental condition, during which the subject walked continuously.

For all conditions, for each trial, the subjects were asked to press quickly on a pressure sensor trigger (attached on the subject’s thumb) when they felt an increase in resistance. This task was realized in a first condition, hereafter referred to as the compensation condition. As the resistance increased, the subjects were asked to maintain their initial walking speed. This required compensating for the spontaneous effects of the continuous variation in resistance on the movement patterns. In the other condition, hereafter referred to as the no-intervention task, as the resistance changed, subjects were instructed to always produce the same propulsive forces, that is not to compensate for any increase in resistance in order to let their stride length and stride frequency adapt freely. It has to be noted that subjects did not seem to have difficulty to perform the two tasks in the same time (one of detection and one of maintain propulsive forces or velocity). The order of the conditions was counterbalanced: three subjects began with the first condition and three began with the second condition.

The treadmill velocity was recorded by an optic transducer fixed to the rotation axle of the treadmill belt. Because the subject was fixed and could not move forward or backward on the treadmill, the treadmill velocity corresponds to the virtual subject’s velocity. A strain gauge joining the belt to the rigid bar recorded the horizontal traction force developed by the subject to drive the treadmill belt. The torque command (to overcome part of the inertia) sent to the treadmill was also recorded. The horizontal front-to-back displacement of the tip of each
foot was recorded by connecting each foot separately to a precision potentiometer. This potentiometer translated a displacement into a voltage. This system allows us to detect the beginning of the stance phase for each foot. Thus, for each stride, the length and total duration could be calculated. The detection time of resistance increase was recorded by a pressure sensor trigger (FSR 151, 10 kΩ to 1 kΩ, delay: 1.5 ms) which was attached to the subject’s thumb. All these data were simultaneously recorded for 600 s with a 100 Hz sampling frequency.

In each block, the last 16 trials were extracted (32 trials in each condition). For each trial, 25 s were extracted: the last 10 s of steady walking, followed by 10 s of increasing resistance before coming back to \( R_0 \) in 5 s.

For each subject, we calculated from the difference between the averaged instantaneous walking velocity profiles observed in the two conditions (\( \text{WVdiff} \)), and then the breakpoint of \( \text{WVdiff} \) shape corresponding to the time when the walking velocity in compensation condition and the walking velocity in no-intervention condition become separated, in order to determine the time when the perturbation begins to affect the behavior. On average, the breakpoint time was equal to 1.91 s.

For the purpose of data analysis, 32 trials per condition were analyzed. For each parameter, ANOVAs with repeated measures were conducted on Subject (6)×Condition (2)×Trial (32). First, we compared, in each condition, the detection time of resistance increase with the starting time of the resistance increase. Secondly, we compared the detection time of resistance increase with the breakpoint time when both walking velocity’s curves of each condition are separated.

3. Results

The first result to mention is that, during periods without perturbations (which lasted randomly from 10 to 20 s), subjects never detect any false perturbation. As shown by Fig. 1, in compensation condition, the averaged detection time of resistance increase (=6.18 s, S.D.=1.75 s) is superior to the breakpoint time (=1.91 s), \( F(1, 31)=585, \ P<0.05 \). At this moment, the subject had compensated 82% of the resistance increase.

In no-intervention condition, the averaged detection time of resistance increase is equal to 6.20 s (S.D.=1.69 s) and again it is superior to the breakpoint time (=1.91 s), \( F(1, 31)=2961, \ P<0.05 \).

The averaged detection time of resistance increase in compensation condition (=6.18 s, S.D.=1.75 s) is equal to those observed in no-intervention condition (=6.20 s, S.D.=1.69 s), \( F(1, 31)=1.13, \ ns. \)

When comparing the variation range of the sensory afferents according to whether it is or it is not linked to the goal, it appears that, in compensation, the subject remains unaware of his force increase (+69%) for a long time, although these modifications go largely beyond the variability range in which he is able to intentionally control his force in no-intervention (=26%). In the same way, in no-intervention, the subject remains unaware of his walking velocity decrease (−10%) for a long time, although these modifications go largely beyond the variability range in which he is able to intentionally control his walking velocity in compensation (=3%).

4. Discussion

In compensation condition, the subject had compensated most of the resistance increase when he detected it 6 s after the perturbation onset. During this period, he voluntarily maintained his stride length and stride frequency—that is to say he used his kinematic afferents of leg movement as a goal feedback—to maintain his walking velocity [1]. Nevertheless, he was not aware of the increase in the force he was producing. Reciprocally, in the no-intervention condition, the subject was focused on voluntarily maintaining his forces. His frequency and amplitude decreased with the resistance increase, but he became aware of his kinematic modifications only 6 s later. Thus, this experiment confirms that the voluntary control of an intended action can function in the absence of awareness of the production of this action [5,7,12]. The models of awareness and control of action emphasize the role of the gap between the desired state and the actual state perceived through sensorial consequences in the awareness of action (for a review, see Ref. [6]). For example, many patients with schizophrenia who have no awareness of their predicted consequences are not aware of controlling their action. In our experiment, the awareness of movement is not based on an error detection between the desired state and the actual state. Indeed, in compensation condition, the motor responses observed for each trial do not show any velocity gap followed by a compensation to reduce the gap. It seems (probably in order to avoid being surprised by the external perturbation—which occurs randomly with short time intervals), that the subject is concentrating on his stride parameters and adopts an on-line control of stride frequency and stride length to keep the same velocity [2]. In both conditions, it is because the feedback of the intended action always informs the subjects about the success of the desired state that the subjects remain largely unaware of the modification of their other sensory inputs. This shows that when the consciousness field is occupied by the intentional control of the main goal and its related feedback, there is a conflict to introduce in the consciousness field other aspects of action linked to the ongoing movement and their related sensory consequences; that is why these latter aspects stay in the background of consciousness for a long time. In fact, there is an inertia effect of the awareness of the stability of goal feedback on the awareness of the modification of the movement sensorial
Fig. 1. The sudden awareness of low level gait pattern production. (A) In compensation condition, averaged walking velocity (thick black line) and averaged horizontal traction force (thin black line) and their averaged within-subjects standard deviations (respectively dashed line and dotted line) observed during a decrease in torque (gray thick line in arbitrary units). The sudden awareness of force increase (vertical continuous line) and its averaged within-subjects standard deviations (two vertical dotted lines). The gray area under the curve of horizontal traction force between 0 and 6.18 s (delimited by the starting time of the resistance increase and the detection time of the resistance increase) represents the unconsciously produced increase in force. The gray area over the curve of walking velocity represents the range of variability in which the subject is able to voluntarily maintain his walking velocity. (B) In no-intervention condition. The legend is the same as before. The sudden awareness of walking velocity decrease (vertical continuous line) and its averaged within-subjects standard deviations (two vertical dotted lines). The gray area over the curve of walking velocity between 0 and 6.20 s represents the unconsciously produced decrease in velocity. The gray area under the curve of horizontal traction force represents the range of variability in which the subject is able to voluntarily maintain his force.
consequences caused by external forces. While the resistance is insufficient for the subject to become suddenly aware of his movement modification, the intentional control of goal feedback affects the awareness of the other sensory sources despite the attention which is turned to them. Indeed, this unawareness of the other sensory sources is all the more surprising since the subject focused on an expected modification of his movement. Which perceptive mechanisms activates this sudden awareness?

The results show that: (1) the subject remains unaware of his force increase in compensation or his walking velocity decrease in no-intervention for a long time, although these modifications go largely beyond the variability range in which he is able to intentionally control his force in no-intervention or his velocity in compensation and (2) the aware detection of resistance increase occurs at the same time in both conditions although the goal control concerns the walking velocity in compensation and the propulsive forces in no-intervention and although the sensory consequences of movement production are linked to propulsive forces in compensation and to walking velocity in no-intervention. These two arguments show that the unawareness of the other sensory sources is all the more surprising since the subject focused on an expected modification of his movement. Which perceptive mechanisms activates this sudden awareness?

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