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RESEARCH ARTICLE

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The broken escalator phenomenon

Aftereffect of walking onto a moving platform

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Abstract We investigated the physiological basis of the 'broken escalator phenomenon', namely the sensation that when walking onto an escalator which is stationary one experiences an odd sensation of imbalance, despite full awareness that the escalator is not going to move. The experimental moving surface was provided by a linear motor-powered sled, moving at 1.2 m/s. Sled velocity, trunk position, trunk angular velocity, EMG of the ankle flexors-extensors and foot-contact signals were recorded in 14 normal subjects. The experiments involved, initially, walking onto the stationary sled (condition Before). Then, subjects walked 20 times onto the moving sled (condition Moving), and it was noted that they increased their walking velocity from a baseline of 0.60 m/s to 0.90 m/s. After the moving trials, subjects were unequivocally warned that the platform would no longer move and asked to walk onto the stationary sled again (condition After). It was found that, despite this warning, subjects walked onto the stationary platform inappropriately fast (0.71 m/s), experienced a large overshoot of the trunk and displayed increased leg electromyographic (EMG) activity. Subjects were surprised by their own behaviour and subjectively reported that the 'broken escalator phenomenon', as experienced in urban life, felt similar to the experiment. By the second trial, most movement parameters had returned to baseline values. The findings represent a motor aftereffect of walking onto a moving platform that occurs despite full knowledge of the changing context. As such, it demonstrates dissociation between the declarative and procedural systems in the CNS. Since gait velocity was raised before foot-sled contact, the findings are at least partly explained by open-loop, predictive behaviour. A cautious strategy of limb stiffness was not responsible for the aftereffect, as revealed by no increase in muscle cocontraction. The observed aftereffect is unlike others previously reported in the literature, which occur only after prolonged continuous exposure to a sensory mismatch, large numbers of learning trials or unpredictable catch trials. The relative ease with which the aftereffect was induced suggests that locomotor adaptation may be more impervious to cognitive control than other types of motor learning.

Keywords Gait adaptation · Aftereffect · Knowledge–action dissociation

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Introduction

Adapting our gait to cope with a predictably moving surface is a common facet of life in modern cities, on escalators and moving walkways. When an escalator is out of order, and therefore stationary, people commonly report that they experience a sway and a vaguely odd sensation, despite knowing that it will not move. This effect may be due to the inappropriate expression of a learned motor behaviour, and so these anecdotal reports may represent a genuine aftereffect of a gait adaptation.

Motor aftereffects have been demonstrated using many different paradigms, and their existence has been interpreted as strong evidence that learning has occurred (Held 1965). For example, when people wear laterally displacing prisms, they initially mis-reach to a visual target and, after a short learning period during which accuracy is regained, they mis-reach again when the prisms are removed, in the opposite direction. Although learning can be assumed from the improvement in performance whilst wearing the prisms, it is the presence of the aftereffect, once the sensory perturbation has been removed, which strengthens this assumption. However, prism adaptation, and its associated aftereffect, may involve perceptual as well as motor adaptation, caused by a mismatch between vision and proprioception (Bedford 1999). In contrast, upper limb aftereffects which are predominantly due to motor adaptation include those occurring after interacting with a manipulandum within a force field (Shadmehr and Mussa-Ivaldi 1994), and learning to reach in the presence of an imposed Coriolis force (Lackner and DiZio 1994). However, it is not clear from these force perturbation studies whether the subject is fully aware of the change in context. In other words, these motor aftereffects may partially be the consequence of unpredictable catch trials.

Aftereffects have also been described within the field of gait and posture. For example, treadmill running causes people to inadvertently drift forwards when attempting to jog on the spot (Anstis 1995), and also results in an illusory increase in walking speed (Pelah and Barlow 1996). Similarly, walking on rotating surfaces causes a subsequent rotational drift (Weber et al. 1998) and a curved gait trajectory (Gordon et al. 1995), while split belt treadmill walking has been shown to result in an aftereffect when estimating the relative speed of each leg (Jensen et al. 1998). Like prism adaptation, these processes result in changes in perception caused by exposure to a sensory mismatch or possibly sensory habituation. Therefore the aftereffect may be the secondary effect of a sensory and/or perceptual adaptation rather than a pure motor adaptation.

In the current study, we used a simple moving-platform task, involving a transient gait perturbation, where full, undistorted sensory feedback was allowed. Subjects were forewarned of the change in context between moving and stationary trials, and so the trial condition was entirely predictable. This study, prompted by the broken escalator phenomenon, therefore investigates the extent to which gait adaptation can be influenced by cognitive input.

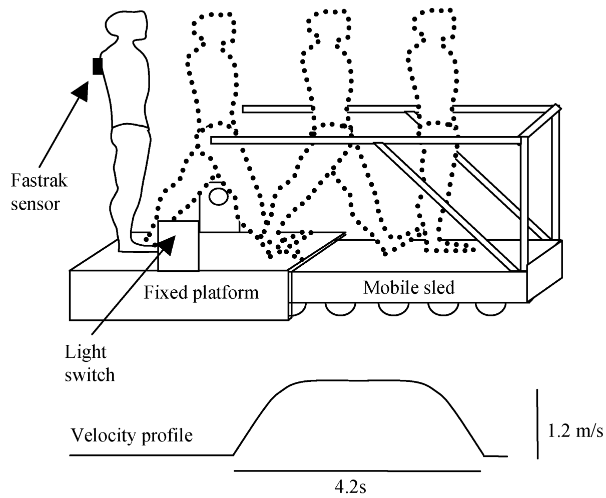

Fig. 1 Experimental apparatus and task. The subject walked from the fixed platform to the sled. During the Moving trials, sled movement was triggered by the leading leg via an infra-red light switch. During Before and After trials, the sled remained stationary. At level C7, an electromagnetic device (Fastrak) recorded trunk linear displacement, from where walking velocity was derived. Trunk angular velocity at the same level was measured with a rate sensor

Methods

Subjects

Ethical approval was received from the local ethics committee. Fourteen healthy subjects gave informed consent to participate in the study (9 men and 5 women; mean age 27.6 years, range 22–36 years). All subjects were naive with regard to the purpose of the experiment.

Apparatus

Subjects walked from a fixed platform onto a mobile sled, which was 172 cm in length and 58 cm wide. The distance between the subject's starting position (as defined by the anterior boundary of the foot) and the front end of the fixed platform was 55 cm. The sled was powered by two linear induction motors, and enveloped by the fixed platform under which it could freely pass (Fig. 1). Movement of the sled was controlled by a computer and could be triggered by gait initiation via an infra-red light switch. When in the starting position, subjects stood immediately behind the infra-red light beam, which was placed 49 cm from the front end of the fixed platform and 31 cm above the surface of the platform, at the level of subjects' shins. A tachometer gave velocity output of the sled. Subject trunk position in the sagittal plane was measured using an electromagnetic tracking device (Fastrak; Polhemus, USA). The sensor was placed over area C7 of the spine. The transmitter was fixed to the mobile sled to remain within range of the subject in all conditions. Trunk sagittal angular velocity was measured using an angular velocity sensor (Watson Industries, USA) on the same area of the back. EMG signals of the medial gastrocnemius and tibialis anterior muscles of each leg were recorded using bipolar electrodes placed 5 cm apart on the belly of the muscle. The EMG signal was bandpass filtered (10–600 Hz). Step timing information was obtained via footswitches placed under the first metatarsal-phalangeal joint and heel, within the subjects' normal footware. Trunk sensors and pre-amplifiers were attached to a harness worn by the subject. All signals were sampled at 500 Hz and transmitted to a computer through cables attached to a pulley system. This arrangement did not impede normal movement of the subject.

Protocol

Main experiment: Fully predictable stimuli

In the main experiment there were no unpredictable or 'catch' trials. All subjects initiated gait with their right leg and made a total of two steps, one on the fixed platform and one which carried them onto the sled, left leg first, where they stopped (Fig. 1). They were instructed to walk at their own pace throughout and to stand still before and after they walked from the fixed platform to the sled. All trials lasted for 16 s, although the time spent actually walking was only 2–4 s, the rest of the time involving quiet stance. Subjects were told to use the hand-rails during moving trials only if absolutely necessary. Ten practice trials were initially performed, during which the sled was kept stationary ('Before' condition). This was followed by 20 moving trials ('Moving' condition) during which the cue to start walking consisted of three beeps. Platform velocity was 1.2 m/s. Sled movement was triggered by gait initiation (leading leg) and started approximately 600 ms before subjects made foot contact with it. Subjects had previously been shown the sled moving to give them some idea of what to expect. After the moving trials were over, a clear verbal warning was given stating that the sled would be kept stationary from then on. They then walked onto the sled 10 more times whilst it was kept stationary ('After' condition) and were subsequently asked to

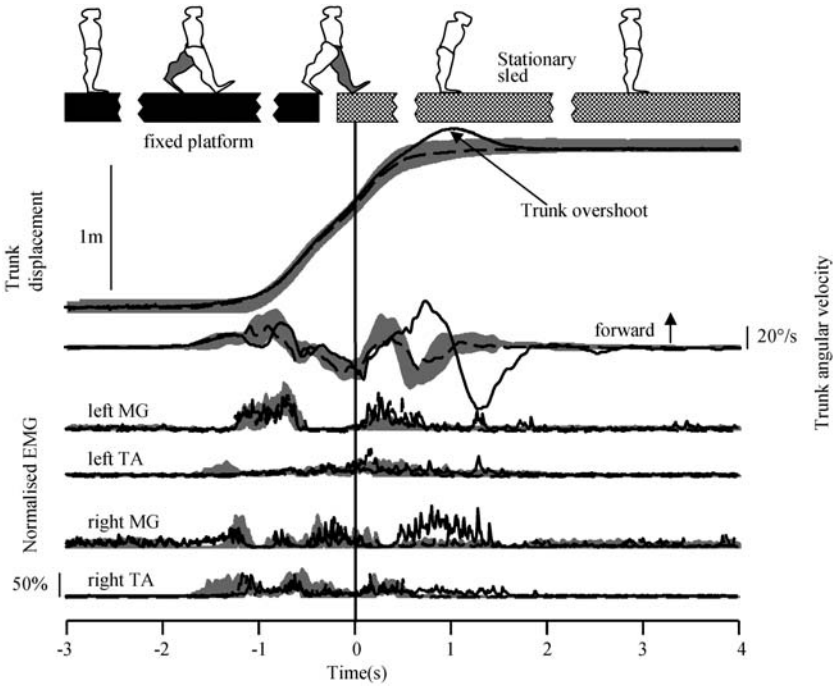

Fig. 2 Representative data from one subject during Before trials and After trials 1 and 2. *Grey bars* represent ±1.96 SD of the mean Before value. After trials 1 and 2 are shown by the *solid and broken black lines*, respectively. The aftereffect observed during After trial 1 is shown at time circa 1 s by the *cartoon at the top* and the *two traces underneath* (trunk displacement overshoot and trunk angular velocity). EMG activity is also enhanced during the 1st After trial, particularly of the right medial gastrocnemius (*MG*)

confirm that they had listened to and understood the prior verbal warning.

Additional experiment: Unpredictable sequence

Once the fully predictable trials were over, the same subjects were then asked to participate in an unpredictable sequence. This was not discussed until the end of the After session, to avoid subjects doubting the veracity of the experimenter during the predictable phase of the experiment. Due to safety and ethical considerations, an absolutely unpredictable trial was not used. Instead, subjects were forewarned that there would be an unknown number of trials, the majority of which would be moving, interspersed by the occasional unannounced stationary trial. This actually consisted of 4 moving trials followed by 1 stationary trial. The purpose of this was to compare any aftereffect which might occur during a predictable stationary trial with that of an unpredictable or, as in this case, a semi-unpredictable ‘catch’ trial.

Analysis

Pre- and post-foot-sled contact epochs were derived from the footswitch data. Trunk position was provided by the Fastrak. For trials where the sled was kept stationary, forward sway was measured as the maximum forward deviation or ‘overshoot’ of the trunk, relative to the mean final resting stance position in the last 3 s of the trial (see top trace of Fig. 2). The Fastrak position sensor was also used to calculate walking velocity, defined as the mean linear trunk velocity in a 0.5-s time window prior to foot-sled contact. EMG signals were rectified and then normalised with respect to the maximal activity induced by standing on tip-toes and pulling toes up as hard as possible, in order to activate the medial gastrocnemius and tibialis anterior muscles, respectively. EMG integrals were taken over a 2-s time window before and after foot-sled contact. To calculate the level of cocontraction, the proportion of time that the leg muscle pairs were simultaneously active was calculated for a 2-s epoch prior to foot-sled contact, which was then normalised with respect to the overall activity during that epoch. A muscle was decreed active if it exceeded 2 standard deviations (SD) of quiet stance levels.

For graphical display of individual data, After trial values were compared with ±1.96 SD of the mean Before values. One-way repeated-measures ANOVA was used to determine the effect of trial number within each condition (general linear model, SPSS version 10). Student paired *t*-tests were used to compare specific conditions, e.g. After trial 1 versus mean Before value. A value of $P<0.05$ was considered significant.

Results

Figure 2 shows representative data for one subject, displaying the Before and After conditions. During After trial 1, there was a large forward sway of the trunk (‘Trunk overshoot’), a large increase in angular velocity of the trunk and increased EMG levels. These parameters had returned to baseline (Before) values by the following trial. These changes indicate the presence of an aftereffect. Each condition of the experiment is now described separately.

Before

All 14 subjects could perform the walking task without difficulty when the sled was kept stationary during the Before condition. All parameters remained stable (Fig. 3, Before). Mean walking velocity and forward sway were 0.60 m/s and 1.8 cm, respectively.

Moving

The moving-platform task was moderately difficult, since all subjects had to make use of the safety hand-rails

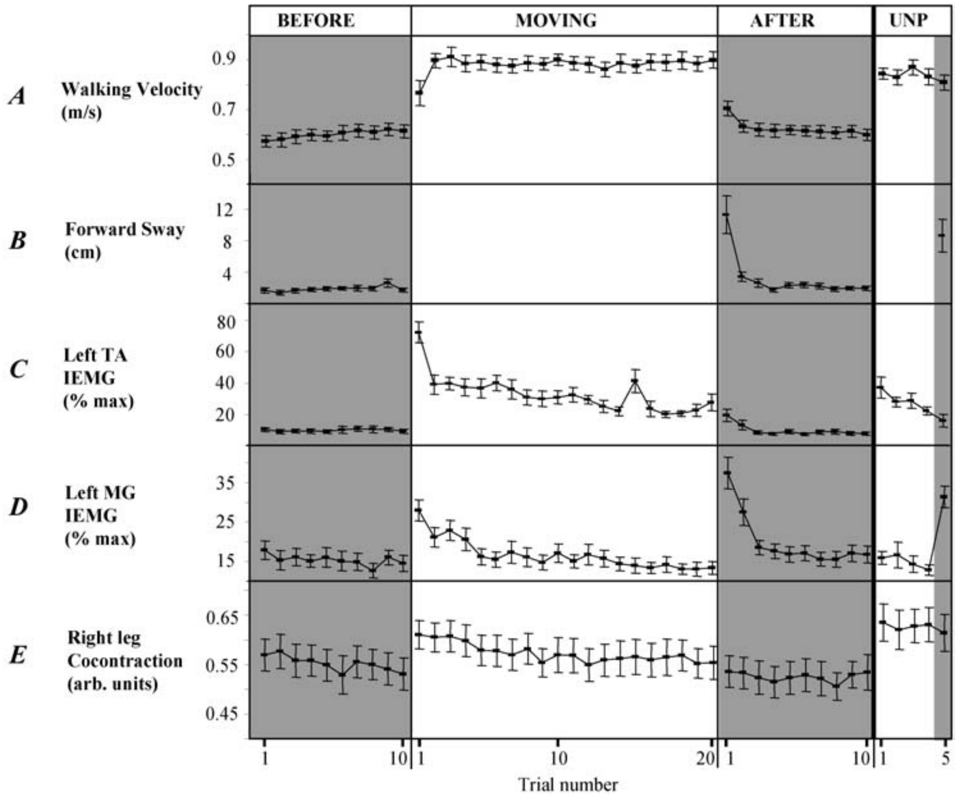

Fig. 3A-D Mean (±SEM, *n*=14) group data during conditions Before, Moving, and After. *Numbers along the horizontal axis* are trial number in each condition. Stationary trials are indicated by a *grey background*, moving sled trials by a *white background*. **A** Mean walking velocity during a 0.5-s time window before foot-sled contact. **B** Maximum forward sway of the trunk relative to final stance position (the data points in the 1st After trial correspond to the trunk overshoot indicated by an *arrow* in Fig. 2). Moving-sled trials are not shown because final stance position could not be normalised due to sled movement, falling movements and occasional hand-rail use by subjects. **C** Integrated EMG activity (IEMG) of the left tibialis anterior (*TA*) and **D** left medial gastrocnemius (*MG*) muscle during a 2-s time window after foot-sled contact. **E** Normalised cocontraction of the right lower leg muscles in a 2-s window before foot-sled contact. The *box* separated by a *thicker vertical line* to the *right of the figure* shows the subsequent unpredictable (*UNP*) experiment, essentially a semi-unpredictable sequence of 4 moving sled trials followed by a single stationary-sled trial

during the first Moving trial, but within five trials all could perform the task without needing to hold on. In anticipation of the moving platform, all subjects spontaneously increased their walking velocity from a mean Before value of 0.60 m/s to 0.77 m/s during the first Moving trial (t=3.702, P=0.003; see Fig. 3A). By the 2nd trial, walking velocity had already reached a plateau value of 0.90 m/s, indicating that subjects quickly learned an appropriate velocity at which to walk. However, adaptation to the postural perturbation induced by the moving platform took longer. This can be seen from the integrated EMG. Figure 3C shows that activity of the left tibialis anterior muscle reaches a stable level only after between 5 and 15 trials.

After

The individual data in Fig. 2 demonstrates a postural aftereffect following the Moving trials. During the first After trial, there was a forward sway of the trunk by 14.9 cm above that of the final resting stance position. This forward sway can also be seen in the trunk angular velocity trace, which shows a large forward rotation of the trunk (peak value 45°/s), immediately followed by a backward rotation (peak value −35 °/s), which returned the subject towards upright stance. Muscle activity reflected these findings. In particular, in this subject, the right medial gastrocnemius muscle showed increased activity above Before values, indicating the required braking activity of the planter flexors in order to arrest the forward sway. By the 2nd After trial, all the parameters had returned back to baseline Before values, lying well within 1.96 SD of the 10 Before trials.

The forward sway (Trunk overshoot) seen in the individual data can also be seen in the mean data in Fig. 3B. The mean forward sway for the first After trial was 11.4 cm; for the remaining After trials, mean forward sway was 2.3 cm. There was a statistically significant difference within the After trials ($F_{9, 117}$=14.57, P<0.001). The first After trial was also significantly larger than the mean Before values of 1.8 cm (t=4.26, P=0.001). Figure 4

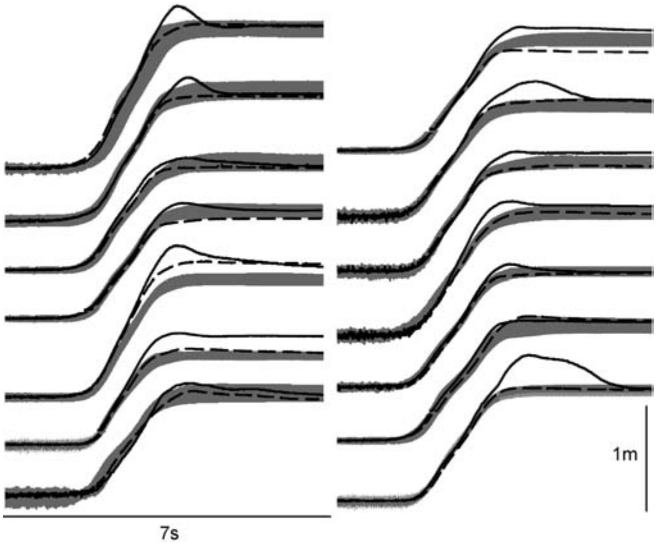

Fig. 4 Trunk displacement for each of the 14 subjects. *Upwards* deviation of traces represents forward displacement of the trunk. *Grey bars* represent ±1.96 SD of the mean Before value. *Solid and broken lines* show After trials 1 and 2, respectively

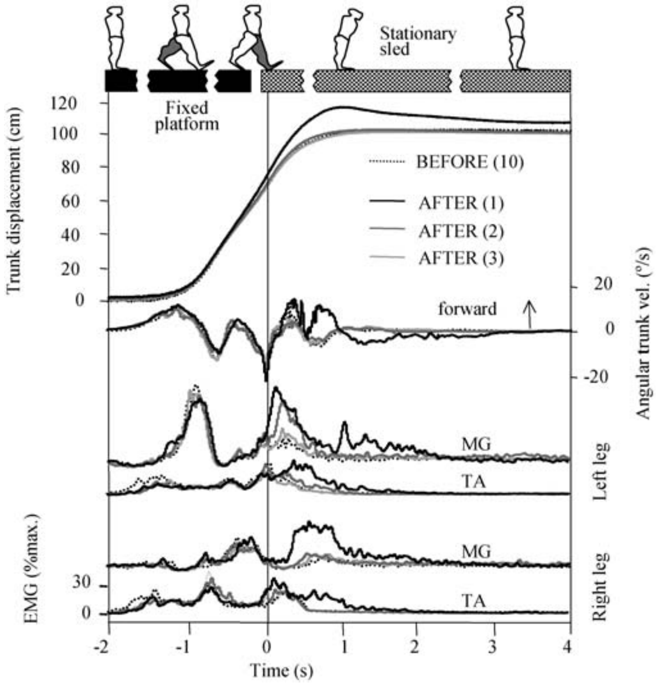

Fig. 5 Mean group movement and muscle responses during the aftereffect. Data is averaged with respect to foot-sled contact, indicated by the *vertical solid line*. The last of the 10 baseline trials, *Before(10)*, is also shown for comparison (obscured by After-trials 2 and 3, if not visible; *TA* tibialis anterior; *MG* medial gastrocnemius)

shows trunk displacement for all 14 subjects; all subjects displayed a forward sway during After trial 1 to a greater or lesser extent.

In four subjects there was not only a large forward sway during the aftereffect, but also the total distance travelled was greater (e.g. Fig. 4, top right trace). This tendency can also be seen in the group mean data in Fig. 5, where the trunk displacement trace shows that the final stance position was 5.4 cm greater in After trial 1 than in Before trial 10 (t=2.31, P=0.038).

Walking velocity during After trial 1 was 0.71 m/s, significantly higher than the mean Before value of 0.60 m/s (t=5.85, P<0.001; Fig. 3B). By After trial 2, this has reached a value of 0.63 m/s, returning to baseline Before values. ANOVA confirms that there was a significant effect of trial upon walking velocity during the After condition ($F_{9,\ 117}$=7.21, P<0.001). The walking velocity during After trial 1 lay between the mean Before value (0.60 m/s) and the plateau Moving level (0.90 m/s), approximately one-third of the way towards the latter. The aftereffect therefore consisted not only of a postural sway, but also of an inappropriately high walking velocity preceding foot-sled contact.

So far the aftereffect appears to be a single-trial effect. Although this was true of most of the parameters measured, EMG activity from the left medial gastrocnemius remained increased above Before values during the 2nd After trial also [t=3.49, P=0.004; see Figs. 3C, 5; integrated EMG Before (mean) 15.41, After (1) 37.4, After (2) 27.5]. This makes sense when we consider that the left leg was the first leg to contact the sled and therefore it had to absorb the initial brunt of the impact to terminate gait.

Subjective reports of the aftereffect

Most subjects spontaneously expressed great surprise and amusement when, on walking on the stationary sled, the aftereffect occurred. When subsequently questioned, however, all confirmed that they had understood and believed the experimenters' warning that the sled would not move. Those subjects who could relate to the broken escalator phenomenon found the experimental aftereffect to be similar to the real-life experience. It is worth noting that, although EMG levels were raised for two trials, subjects only perceived an aftereffect during the 1stAfter trial.

Unpredictable

In this complementary experiment, subjects were made aware that the platform would be unexpectedly stationary at some point during the unpredictable condition. This knowledge caused them to slightly, but significantly, lower their walking velocity during the 4 unpredictable trials where the sled moved (UNP), compared with the Moving trials (0.84 m/s compared with 0.89 m/s; t=4.08, P<0.001; Fig. 3A). When the sled was unexpectedly stationary on the 5th trial, however, they were unable to react quickly enough to significantly lower their walking velocity further ($F_{4,\ 52}$=1.74, P=0.16). This was despite the fact that, during all moving trials, they were afforded approximately 0.5 s of visual and auditory exposure to the moving sled before they made contact with it. Forward sway was 8.64 cm, not significantly different from the After trial 1 value of 11.4 cm (t=1.09, P=0.29).

Cocontraction

When presented with a potential threat to balance, people tend to employ a strategy of limb stiffness (Carpenter et al. 2001). Also, agonist–antagonist cocontraction has been shown to decrease as a consequence of motor learning(Osu et al. 2002) Therefore, in order to gain insight into the strategy employed by subjects, the degree of cocontraction of agonist–antagonist pairs was calculated for each leg, before foot-sled contact. Figure 3E shows that for the right leg, which acted as the stance leg propelling the subject from the fixed platform onto the sled, there was an increase in cocontraction during the start of the Moving session, which reduced as people learnt the task ($F_{19,\ 247}$=3.90, P<0.001). However, there was no such increase occurring during the initial After trials ($F_{9,\ 117}$=0.91, P=0.52). Instead, the level of cocontraction was similar to that of the Before trials (mean Before 0.552, mean After 0.525) and remained quite stable. Also, during the unpredictable trials, the mean level of cocontraction was higher than in all other conditions (mean Unpredictable 0.625; $F_{3,36}$=3.95, P=0.016). Therefore subjects were not employing a strategy of anticipatory limb stiffness when the aftereffect occurred, although they did use this strategy when adapting to the moving platform, and when the trial condition was unpredictable.

Discussion

We demonstrated an aftereffect of walking onto a moving platform that occurred despite full knowledge that the platform would no longer move and the fact that it had been experienced previously as stationary. This aftereffect manifested itself as an inappropriately high walking velocity and a large, subsequent forward sway, as revealed by an overshoot in trunk displacement caused by a forward rotation of the trunk. This was also reflected by increased muscle activity in the lower leg. The aftereffect was mostly extinguished after a single trial, although EMG activity remained significantly above baseline levels for two trials.

The subjects' subjective reports underlined a similarity between the experimental aftereffect and the urban-life broken escalator phenomenon. Although we have not found scientific literature on the broken escalator phenomenon, there appear to be three possibilities to explain its occurrence: (1) it could be a pure illusion without any motor correlates; (2) it could be a reactive mechanism, i.e. a postural conditioned reflex, triggered by foot contact with the sled (or escalator) previously experienced as moving; or (3) it could be an open-loop mechanism, i.e. operating before foot-sled contact. The recordings of walking velocity, showing that gait velocity was inappropriately high prior to foot-sled contact, would favour the latter option. Whereas the experiments reported here cannot entirely rule out a component of illusion or contact-triggered postural reflex, at least we have identified an open-loop predictive mechanism underlying the observed aftereffect and, possibly, the broken escalator phenomenon.

A dissociation between knowledge and action

As a consequence of learning to walk onto the moving platform, all subjects developed an increase in walking velocity. This increase persisted into the 1st After trial, meaning that subjects walked faster, as if they were anticipating that the platform might continue to move. However, all subjects confirmed that they had understood and believed the experimenter's warning that it would not move. The increase in walking velocity during After-trial 1 was approximately one-third of the way towards that during the Moving condition. Hence, subjects did not behave as if the stationary trial was completely unexpected, but slowed down somewhat. In other words, the motor system did take some heed of the warning of impending stationarity.

In studies using upper-limb adaptation paradigms, it has been shown that, when faced with an unpredictable sequence of trials, the motor system 'hedges its bets', acting to cope with the mean perturbation (Scheidt et al. 2001). However, for any given individual trial, a prediction is made based upon at least the last three trials (Scheidt et al. 2001; Witney et al. 2001). Here, even when the trial condition is entirely predictable due to an unequivocal warning, the motor system still seems partially constrained by this statistical mode of operation. Specifically, it uses the previous moving platform trials to make a judgement about the subsequent context, ignoring conscious knowledge to some extent. The resultant walking velocity, intermediate between that appropriate for either the stationary or moving conditions, illustrates partial independence of the declarative and procedural systems in the CNS. Although dissociations between perception and action have been demonstrated before, they usually involve examples of the motor system acting appropriately even when cognition or perception are incorrect, e.g. appropriate motor performance in the presence of visual illusions (Carey 2001). However, we show the opposite, that the motor system acts inappropriately even though perception and cognition are veridical.

Reaching experiments also suggest that the motor system cannot readily switch between two newly learned behaviours, even when the change in context is predictable (Karniel and Mussa-Ivaldi 2002). This has been interpreted as meaning that the CNS has a strong tendency to employ only a single internal model when dealing with sequences of perturbations. This is consistent with the present finding. However, in the present experiment there is only one learning task, namely adapting to the moving sled. Walking onto stationary ground is presumably not something we need to learn, since we have been doing it most of our lives. Therefore it is rather surprising that our ability to switch back to this most natural of tasks is impaired after a brief adaptation period.

A cautious gait strategy was not observed

Previous studies have shown that predictive changes in gait and posture occur when anticipating a potential threat to balance. (Marigold and Patla 2002; Pijnappels et al. 2001; Pavol and Pai 2002). These experiments involve the use of unpredictable trials and demonstrate cognitive control of the motor system when the base of support is perceived to be uncertain. Conversely, the presently described aftereffect suggests a failure of this control mechanism, since the base of support is cognitively known to be stationary, yet subjects walk onto it as if its state was uncertain. Cham and Redfern (2002) showed that when subjects walk onto a previously slippery surface, they display cautious gait biomechanics, despite being made aware that the surface was no longer slippery. Full vision of the floor was prevented in their study. Nevertheless, it raises the possibility that the currently described aftereffect could simply be a consequence of subjects displaying cautious behaviour in a potentially dangerous environment. It may well be less dangerous to assume that the platform will move when it actually will not, than to make the opposite mistake.

In the Moving condition, right leg muscle cocontraction prior to foot-sled contact was initially higher than baseline and tailed off as subjects became acquainted with the task. Also, during the unpredictable trials, cocontraction levels were higher than in all other conditions and walking speed was slightly lower than during the Moving condition. This agrees with previous studies showing that cocontraction is reduced as a consequence of learning (Osu et al. 2002), and that a cautious gait strategy is observed when the support surface is unpredictable (Carpenter et al. 2001). However, forward sway during the unpredictable stationary trial was not significantly greater than that of the aftereffect during the predictable After trial 1. The reason for this could be that when subjects know the trial condition is unpredictable, the speed and gain of their compensatory postural response is increased, resulting in a lower forward sway during the catch trial than might be expected. An entirely unpredictable stationary trial (not used due to safety considerations) might be expected to cause a much larger forward sway. The finding that muscle cocontraction was increased during the unpredictable condition supports the view that they were cautious and anticipating having to react quickly.

During the After condition, however, there was no such predictive increase in muscle cocontraction, that is, a strategy of limb stiffness was not present. This suggests that subjects did not employ a cautious strategy as if they were anticipating a postural threat (Carpenter et al. 2001) or actively suppressing an inappropriate postural response. The fact that most subjects displayed great surprise at the aftereffect also suggests that it was not the consequence of a cognitive strategy of cautiousness, or any high-level cognitive behaviour at all, for that matter. This element of surprise might be explained by the high sensitivity of the motor system to discrepancies between predicted and actual sensory feedback (Wolpert and Flanagan 2001).

A motor, not sensory, adaptation

Aftereffects which occur even in predictable environments have been previously reported in the field of gait and posture (Anstis 1995; Gordon et al. 1995; Jensen et al. 1998; Weber et al. 1998). There are crucial differences, however, between these studies and the current one. Firstly, all of these aftereffects have been elicited only when visual feedback has been deprived after the adaptation process has occurred. Secondly, the adaptation processes themselves may involve sensory deprivation or mismatch, meaning that the subsequent aftereffect may be secondary to sensory and/or perceptual adaptation. For example, the aftereffect of running on a treadmill has been attributed to a sensory recalibration caused by the absence of concurrent visual flow that signals forward movement (Durgin and Pelah 1999). This results in forward motion while jogging on the spot, although, crucially, people perceive no movement. Treadmill running also results in an illusory increase in subsequent walking speed (Pelah and Barlow 1996). Likewise, walking on rotating surfaces or a split-belt treadmill both result in perceptual aftereffects, with regard to subjects' estimation of locomotor trajectory (Gordon et al. 1995) and leg speed (Jensen et al. 1998), respectively. Thirdly, the adaptation processes in these experiments all involve continuous and prolonged exposure during the adaptive phase, ranging from 10 min to 2 h. Indeed, the aftereffect of walking on a rotating surface, whilst shown not to be due to a sensory mismatch, has been explained by an habituation process caused by either continuous, long-lasting sensory stimulation or, alternatively, constant efferent activity (Jurgens et al. 1999). In stark contrast to these experiments, the present study involved an adaptation process consisting of a small number of short-lasting discrete trials, each involving a transient gait perturbation with full normal sensory feedback. It could be argued that when standing on the moving sled there was a period of sensory conflict, due to the presence of visual flow conflicting with the lack of sensory information from the legs signalling forward movement. However, this period of potential conflict was less than 4 s for each trial, with a gap of at least 20 s between trials. Also, at the end of each moving trial, subjects were exposed to exactly the opposite sensory conflict, when they were moved backwards to the start position, which would presumably negate any such effect. In summary, it is very unlikely that the conditions required to produce sensory and/or perceptual adaptation were present. Therefore the aftereffect described here must be the consequence of motor adaptation alone.

This distinction between sensory and/or perceptual learning and motor learning has been made with reference to prism-induced reaching adaptation, a much-studied aftereffect paradigm. Although the mechanism of prism adaptation is not yet fully understood, part of the adaptation process involves a change in visual perception (Bedford 1999). When adaptation to prisms occurs in the absence of such perceptual learning, by substituting real feedback of hand position with virtual feedback, little or no aftereffect occurs and generalisation is reduced (Clower and Boussaoud 2000; Norris et al. 2001). In the light of this finding, and if our conclusion is correct that the moving-platform task does not induce perceptual adaptation, it is surprising that it causes any aftereffect at all. The existence of the aftereffect therefore suggests that gait adaptation is relatively independent of those brain mechanisms involved in declarative knowledge. The fact that locomotion is mediated by a phylogenetically old system, involving autonomous spinal networks, is consistent with this viewpoint (Bizzi et al. 2000).

Conclusion

We have described an aftereffect of walking onto a moving platform which occurs despite full awareness of the changing context. This finding may underlie the commonly experienced broken escalator phenomenon and illustrates dissociation between declarative and procedural systems in the CNS. It occurs after as few as 20 discrete and brief adaptation trials, without the conditions necessary to produce sensory and/or perceptual adaptation. The remarkable ease with which it is induced suggests that locomotor adaptation may be more impervious to cognitive influence than other types of motor learning.

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