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Timing of preparatory landing responses as a function of availability of optic flow information

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Abstract

This study investigated temporal patterns of EMG activity during self-initiated falls with different optic flow information ('gaze directions'). Onsets of EMG during the flight phase were monitored from five experienced volunteers that completed 72 landings in three gaze directions (downward, mid-range and horizontal) and six heights of fall (10–130 cm). EMG recordings were obtained from the right gastrocnemius, tibialis anterior, biceps femoris and rectus femoris muscles, and used to determine the latency of onset (L_o) and the perceived time to contact (T_c). Impacts at touchdown were also monitored using as estimates the major peak of the vertical ground reaction forces (F_{max}) normalized to body mass, time to peak (T_{max}), peak impulse (I_{norm}) normalized to momentum, and rate of change of force (dF_{max}/dt). Results showed that L_o was longer as heights of fall increased, but remained within a narrow time-window at >50 cm landings. No significant differences in L_o were observed when gaze direction was changed. The relationship between T_c and flight time followed a linear trend regardless of gaze direction. Gaze direction did not significantly affect the landing impacts. In conclusion, availability of optic flow during landing does not play a major role in triggering the preparatory muscle actions in self-initiated falls. Once a structured landing plan has been acquired, the relevant muscles respond relative to the start of the fall.

Keywords: Visual information; Optic flow; Preparatory responses; Landing impacts

1. Introduction

The study of landing responses has not only practical and functional implications, but also theoretical significance for understanding vestibular and visual motor control in humans [8–10,22,23] and animals [4,20,28]. Gibson [6] suggested that when people are confronted with an object in a collision course, the triggering and modulation of their motor actions is dependent on the perceptual visual input that occurs between the interaction of the moving observer and objects or nearby surfaces. However, the triggering mechanism will occur only if the observer perceives its necessity (i.e., if he/she perceives an 'affordance' [31]). Affordances may perceive via optic invariants such as tau (τ) [13–15], which provides information about the time to contact (T_c) with a surface in a collision course. Tau is optically defined as the inverse of the rate of dilation of the environmental layouts projected onto the retina of the eyes. Its functional significance lies in that at critical values of τ (τ_{margin}), a coordinated set of motor actions is triggered. Support for the implementation of such a strategy during free falls came from the animal study of Lee and Reddish [16]. These authors observed that gannets plummeting into the sea avoid crashing by using visually perceived time to contact information. Their measure-

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ments showed that the birds begin their wing folding actions at τ_{margin}. However, time to contact information may be used without necessarily implementing a τ heuristic [27]. Houseflies tune the leg extension movements before touchdown on a surface based on visually perceived time to contact information, but may not use that strategy [32]. Srinivasan et al. [28] showed that honeybees modulate landing speed on flat surfaces by implementing a 'constant time to contact' strategy, and not a strategy based on critical values of τ. They keep the angular velocity of the expanding visual image at a constant value by decreasing the speed of descent at a rate that is proportional to the decrease in horizontal speed.

In humans, Sidaway et al. [26] argued that a τ_{margin} strategy based on time to contact information is implemented when subjects land from self-initiated falls of different heights. Such an early preparation for landing is based on prospective visual information about the moment of touchdown, and should allow for the anticipatory build-up of tension in the relevant musculature in order to reduce the risk of injury at collision with the ground. However, empirical support for such an assumption is rather limited for normal heights of fall. Santello et al. [25] found no differences between vision and no-vision landings in the preparatory EMG responses during the flight, but reported that joint stiffness and impact forces increased in no-vision trials after touchdown. This may suggest that a visual modulation of the preparatory muscular activity may not be used in landings from regular heights of fall in known experimental environments. Instead, the landing preparation may be structured (pre-programmed) and triggered relative to the moment of the initiation of the fall.

The possibility that the triggering response takes place at a constant timing after the start of the fall is an interesting hypothesis. We refer to this alternative as the 'constant time from release' hypothesis based on the assumption that the temporal muscle patterns associated with the free-fall are not dependent on the optic flow of information arriving to the eyes.

In the present study, we used a landing paradigm comparable to that of Santello et al. [25] and investigated temporal patterns of muscular activation under conditions that maximize, reduce or completely preclude the availability of optic flow information. This was done by instructing subjects about the gaze direction before the free-fall started, by maintaining the same gaze direction during the fall, and by wearing appropriate goggles that constrained gaze direction but did not prevent vision. We were particularly interested in determining what stimulus triggers the EMG activity and how this activity is modulated during the flight. An additional goal of this study was to test the assumption that early pre-landing actions contribute to the reduction of the impacts at touchdown.

2. Methods

2.1. Subjects and design

Following approval of the research protocol by the institutional review board, five healthy men (20.4 ± 0.6 years; 178.7 ± 6.5 cm: 77.4 ± 8.1 kg) volunteered to serve as subjects for this investigation. All subjects were experienced in landing performances (>100 parachute descents each), and gave written informed consent to participate in the study after receiving explanations of all the procedures, risks and benefits. During the experiment, they performed landing jumps from 10–30 cm, 30–50 cm, 50–70 cm, 70–90 cm, 90–110 cm, and 110–130 cm height of fall categories in three different gaze direction conditions (horizontal gaze, mid-range gaze, and downwards gaze). Each subject completed 72 landings in total (four trials in each of six heights and three gaze directions, in a semi-counterbalanced order).

2.2. Apparatus

The self-initiated landings were performed from a customized platform that was designed to allow easy adjustments to all required heights. Subjects were instructed to stand at the edge of the platform and activate a 5 V electromagnetic switch interfaced to a computer. The computer detected a sudden drop to 0 V upon release of the switch and used this to trigger the data collection process. Data were buffered during a period of 0.5 s prior to the release of the switch, and were further stored for the following 2.5 s. The landing surface consisted of a force plate (Model 9261 Kistler Inc., Switzerland) connected to suitable charge amplifiers, which measured vertical ground reaction forces (VGRF). The switch, force and raw EMG signals were A/D converted, and sampled for a total of 3 s at a rate of 1 KHz (Keithley 1601, National Instruments Inc., USA). These data were stored and analyzed off-line on PC using custom-made software.

Landings were also video taped (60 Hz, Panasonic Inc., Japan) to analyze planar patterns of joint motion during the flight (i.e., ankle and knee angular displacement–time curves). The video recordings were synchronized with the analogue data. This was done by using a bright narrow-angle light emitting diode (LED, A&D 180 HRP, 12,000 mcd, 8°) that was turned on when the subject closed a circuit by pressing the switch. At take-off the switch was released, the voltage dropped to zero, and the LED was turned off. This was captured by the video camera and used as the common event for off-line synchronization.

2.3. Procedures

Subjects were allowed to practice during a 10 min warm-up period. They were instructed to self-initiate