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Short communication

Digital video combined with conventional radiography creates an excellent high-speed X-ray video system

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Abstract

Analysing rapid internal movement in animals requires high-speed X-ray imaging to visualise motion of bony and soft body structures. The frame rate of X-ray cinematic camera is limited to 200 frames s^{-1} with a shutter speed of 1/3000 s, due to the low X-ray kV, required for small animals. These rates are often too slow for analysing the rapid accelerations of which small animals are capable. Here, we present three alternative digital-video systems that can be combined with a conventional X-ray intensifier to yield excellent slow-motion images of internal body parts of small animals. Each system shows high performance for different requirements of radiographic motion analysis.

Keywords: High-speed; X-ray; Digital; Video; *Chameleo melleri*; *Hydromantes imperailis*

1. Introduction

In biomechanical research, high-speed X-ray recording of inserted radio-opaque markers is indispensable to analyse movements in muscular–skeletal systems. The conventional cine-radiography system that is used in our laboratory is Philips Optimus M 200 with a maximum rate of 150 frames s^{-1}. This is too slow for the analysis of fast movements. Also, the refresh rate of the conventional X-ray video is maximally 50 Hz, which often results in blurred motion. Previously, analogue high-speed video in combination with X-ray has been used to analyse fluid movements (Mishima et al., 1997), and to capture motion of artificial heart valves (Naemura et al., 1997). In both studies the images were realised by increasing the voltage to 100 kV at 500 fields s^{-1} resulting in lack of detail and contrast. The high sensitivity, modern video systems make recordings at 65 kV possible, which is a maximum voltage for small animals. The results of X-ray-video recordings are described for three different digital video systems, combined with a Philips Optimus M 200 X-ray apparatus. The systems were tested during feeding experiments of *Hydromantes imperialis* (Deban et al., 1997; Deban and Dicke, 1999) and *Chameleo melleri* (de Groot et al., 2000; de Groot et al., in preparation). Both species feed on small prey using rapid tongue projection. *Hydromantes imperialis* projects the tongue up to 6 cm in about 20 ms, and *Chameleo melleri* projects the tongue over a distance of 35 cm in about 50 ms. Since the tongue projection initially occurs inside the mouth, X-ray is required to visualise the entire tongue movement.

2. Materials and methods

In the first experiment, the intensifier of the Philips Optimus M 200 X-ray apparatus was combined with a Sony MiniDV DCR-TRV900 camcorder (US model running at 60 fields s^{-1}, shutter speed 1/1000 s). Small lead markers ($\sim 1\,mm^2$) were glued to the central cartilage of the extremely long tongue, to the cartilage in the floor of the mouth and to the tongue protractor muscles. For the second experiment, a *Chameleo melleri* was anaesthetised and markers were glued to the tongue. The first recordings were made with a JVC GR-DVL9500 digital video camera at 100 fields s^{-1}, shutter

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speed 1/500 s. In the third experiment the JVC was replaced with a Kodak Motion Corder Analyzer SR-500 s that records at 500 fields s^{-1}, shutter speed 1/2000 s. The images are loaded into the camera's onboard memory, and were saved on digital video (Sony GV-D900E) or directly on the computer hard disk. The maximum recording time at 500 fields s is 8.7 s. The X-ray dose was in every experiment 63 kV, 30 mA, applied continuously. The experiments were authorised by the local ethical committee on animal experiments (U-DEC98022).

3. Results

Because of the small size of *Hydromantes imperialis*, the Sony Mini DV DCR-TRV900 camcorder was used, which incorporates a macro zoom lens and was focussed on a plastic box ($100 \times 66 \times 20$ mm), which contained the feeding salamander. The high shutter speed ensured a non-blurred view of the lead markers at the relatively slow frame rate (Fig. 1). The recordings with the JVC GR-DVL9500 of *Chameleo melleri* result in a clear view of the lead markers and the anatomical structures

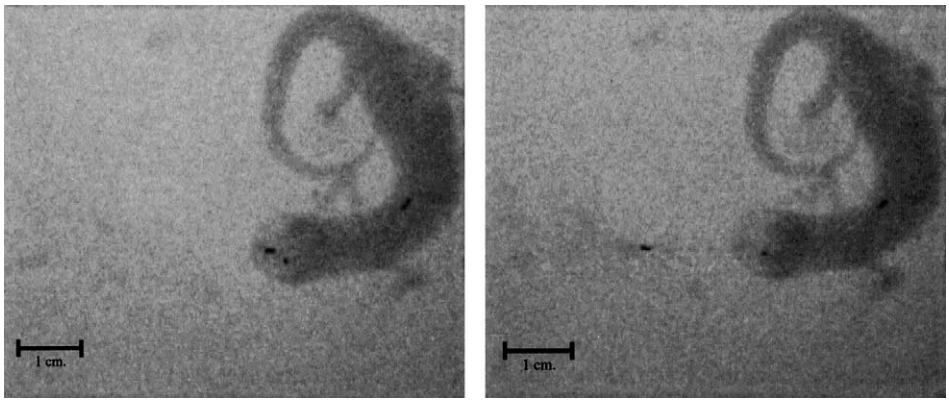

Fig. 1. *Hydromantes imperialis* during feeding from dorsal view. The left frame shows the salamander with the mouth closed. The right frame shows the tongue protracted ~1.5 cm to catch a cricket. Images were captured at 60 fields s^{-1} with a shutter speed of 1/1000 s.

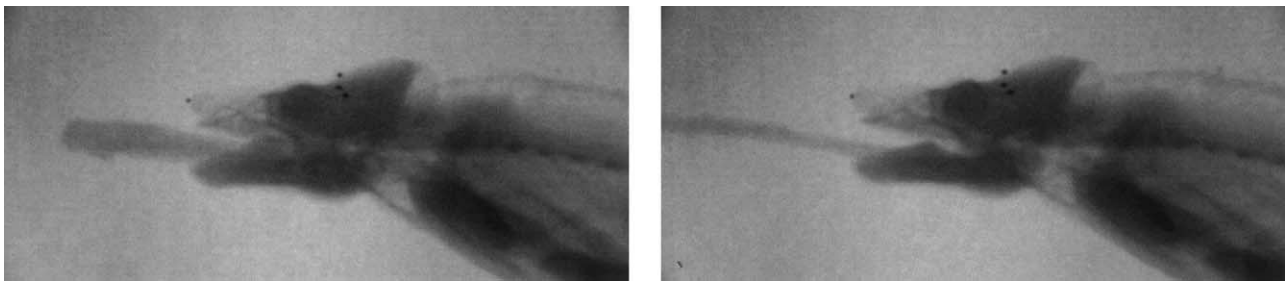

Fig. 2. *Chameleo melleri* during feeding from lateral view. The left frame shows the chameleon protracting the tongue pad out of the mouth, fixating on the prey with nearly closed mouth, In the right frame the tongue was protracted to catch the prey. Capture at 100 fields s^{-1} with a shutter speed of 1/500 s.

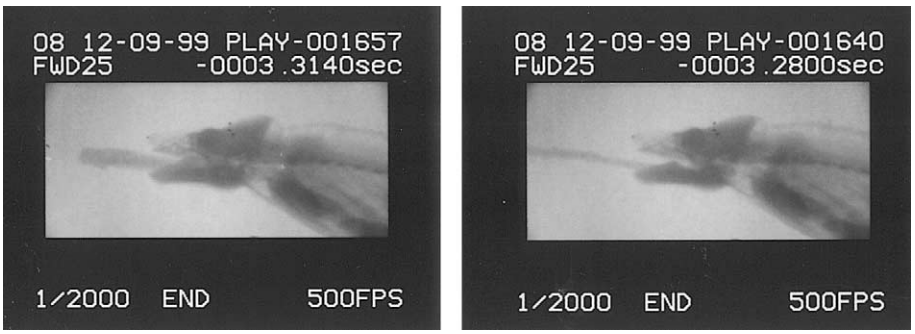

Fig. 3. *Chameleo melleri* during feeding from lateral view. The left frame shows the chameleon with the tongue pad out of the mouth, fixating on the prey with nearly closed mouth. The right frame shows the tongue protracted to catch the prey. Capture at 500 fields s^{-1} with a shutter speed of 1/2000 s.

(Fig. 2). In the last part of the projection, a slight motion blur occurs due to the high tongue velocity of about $6\,m\,s^{-1}$. By using the Kodak Motion Corder Analyzer SR 500s, the results reveal excellent X-ray video without any motion blur, at a frame rate that even enables reliable measurements of the acceleration (Fig. 3).

4. Discussion

These experiments show that a conventional X-ray apparatus can be combined with a flexible choice of conventional digital video systems. The Sony camcorder at 60 fields s^{-1} with a shutter speed 1/1000 s, resulted in sharp images of the markers on the tongue. However, the framing rate was too low to accurately capture the maximum tongue projection. The zoom function enlarged the image of the small salamander more than would be possible with conventional X-ray cinematography. The JVC performs with 100 fields s^{-1} intermediate to the Sony and Kodak system. The maximum shutter speed of 1/500 s is too slow to capture the high-velocity events. The digital Kodak Motion Corder Analyzer SR series showed the highest performance when upgraded to 1/1000 frames s^{-1}; it permits zooming closely on small animals as well as immediate replay of image sequences. One drawback of the Kodak system is the limited recording time of 8.7 s at 500 frames s^{-1} which made it necessary to download the image sequences in-between the events for permanent storage. The high speed of the JVC and Kodak systems are realised by partial scan, so the image has half the number of pixels in height. There are apparently no limitations to the frame rate of recordings by a digital video camera of the X-ray image intensifier, apart from light sensitivity and resolution of the video-imaging chip. The Sony and JVC consumer cameras may not be the best solution for every problem in X-ray movement analysis, but they are low budget systems with excellent digital image quality.

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