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String-pulling for food by the rat: Assessment of movement, topography and kinematics of a bilaterally skilled forelimb act

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ABSTRACT

A variety of behavioral tests have been developed to assess skilled forelimb function in the rat, including tests that assess use of a single limb in reaching for food and placing it in the mouth for eating. The present study describes bilateral hand use in string-pulling to obtain a food reward. The movement consists of alternating forelimb movements in which a limb is advanced to grasp a string and withdraw it toward the body in order to retrieve a food reward. The movements of aim, advance, grasp, pull and push are associated with hand shape changes including collect, overgrasp, grasp and release. The topography and kinematics of limb and hand movement are assessed by digitizing methods that derive trajectory, distance, and velocity measures. The task is acquired by a rat within a few days of training, features few missed grasps, shows improvements with practice, and yields dozens of independent reaches by each hand in a single test session. The present analysis provides simple methods for describing each independent forelimb and hand movement and its topographic and kinematic properties. The similarities between string-pulling and other rat forelimb movements are discussed in relation to the idea that rat forelimb movements are conserved in tasks such as string-pulling, walking, reaching for food and grid walking. The task is also discussed with respect to its potential to investigate neural and cognitive bases of fine motor control.

1. Introduction

Beginning with Köhler's (1927) demonstration that apes display insight learning in adapting objects to serve as tools for retrieving a food reward, there have been many demonstrations of tool or prototool use in animals. One example of prototool use is string-pulling, in which an animal pulls on a string to gain a food reward attached to its end. String-pulling has been taught to or spontaneously displayed by a wide range of animal species (Kolb, Cioe, & Comeau, 2008; Osthaus, Lea, & Slater, 2005; Whishaw, Tomie, & Kolb, 1992; Whitt, Douglas, Osthaus, & Hocking, 2009). It is very likely that string-pulling falls within the natural repertoire of many animals because it is akin to pulling on nesting material, pulling on a food object that an animal wants to retrieve, pulling on a branch that might contain a food item, or pulling on a tall blade of grass that contains seeds on its end. In a typical string-pulling act, an animal pulls on a long piece of string in order to reel in a food reward tied at the end. String-pulling behavior has been used to investigate a range of cognitive processes (for review see Jacobs & Osvath, 2015). For example, combining string-pulling with visual discrimination learning has provided insight to the variability in means-end learning observed among different species of parrots (Krasheninnikova, Bräger, & Wanker, 2013). Rats have been trained to use olfactory and tactile cues during string-pulling behavior to

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investigate the neurobiology of mnemonic function (Köppen et al., 2016; Whishaw & Tomie, 1991). String-pulling behavior has also been adapted for bumblebees to investigate social learning (Alem et al., 2016).

The adaptability of string-pulling behavior has provided a robust tool for comparative cognition; however, research has yet to characterize the organization of the fine motor movements used by the rat for string-pulling behavior. In the present study a combination of measurement approaches are used to investigate rat string-pulling. It has been argued that human and non-human primate manipulatory scale voluntary movements depend on a hand-centered representational system (Gordon, Ghilard, & Ghez, 1992). Electrophysiological (Brown & Testkey, 2014; Graziano, 2008; Kaas, Gharbawie, & Stepniewska, 2013) and behavioral (Gordon, Ghilardi, & Ghez, 1994, Gordon, Ghilardi, Cooper, & Ghez, 1994) approaches have provided evidence that this representational system separately encodes the type of movement as well as the movement's direction and distance. Provided that a similar representational system is conserved in rats, then components of string-pulling behavior should exhibit organizational characteristics consistent with direction and distance estimation. For example, human participants modify their manipulatory scale movement kinematics (peak speed) to the extent of the movement (Gordon, Ghilardi, Cooper et al., 1994). A similar relationship has been observed in rat ambulatory scale exploratory behavior (Wallace, Hamilton, & Whishaw, 2006). It remains to be determined if this relationship is observed in movements at the rat manipulatory scale.

The current study uses qualitative and quantitative analysis techniques to investigate the movement organization associated with string-pulling behavior in rats. Qualitative analysis involves characterizing forelimb and hand movements engaged during string-pulling. Quantitative analysis uses motion capture software to investigate the topographic and kinematic characteristics of the functional units that emerged from the qualitative analysis. The results of this work establish a foundation for future research to investigate manipulatory scale movement organization observed across a variety of animal species.

2. Materials and methods

2.1. Subjects

Male Long Evans rats (n = 5) were obtained from the Northern Illinois University vivarium at 90 days of age and group housed in opaque plastic cages with wire mesh tops. Throughout testing rats were maintained at 85% of their ad lib weight, and the colony room was maintained at 20–21° with 12-h light/dark cycle. All experimental protocols were approved by the NIU Institutional Animal Care and Use Committee. These naïve rats were a subset of the animals in a larger project investigating the effects of cortical devascularization on fine motor control.

2.2. Apparatus

A rectangular transparent cage (46 cm × 26 cm × 26 cm) with a wire mesh top and an opaque barrier restricting access to half the cage served as the string-pulling apparatus (see Fig. 1). The apparatus was placed on table in a small room with many visual cues. The string (0.2 cm in diameter) was 100% cotton that varied length from training (100 cm) to testing (150 cm) with a weight attached to the end of the string in the cage, preventing the string from falling out of the apparatus. A JVC HD video camera (Model #: GY-HM100U) was positioned perpendicular to the wall of the apparatus with the string. The resulting videos were stored on DVDs for subsequent offline analysis.

Fig. 1. Photo of the apparatus with a subset of the strings used during training (left panel) and testing (right panel).