The kinematics of colobine locomotion, particularly the folivorous primates of Jodhpur, has to date received little attention. Recent study at Jodhpur troops is the first to examine kinematics during arboreal quadrupedal locomotion in these leaf monkeys, revealing marked differences in tail postures among age category, sex and rank order of Hanuman langur (Semnopithecus entellus). During symmetrical walking, females typically allow the tail to hang down, falling along the substrate behind them during travel. Alpha male of bisexual troop often arcing the tail higher in concave downwards posture. There is the greatest variability in tail posture, often raising the tail in a concave-upwards arc with the tip reaching over the thorax. These patterns are evident in our kinematic data, and may reflect different adaptations to rapid locomotion over varied substrates in the wild. Whereas doucs are typically observed in arboreal settings and utilize forelimb suspensory movements when traveling rapidly. During quadrupedal walks, the trunk is stabilized. Whereas, the head is frequently rotated through more than 20° about the pitch axis and up to 90° to the left or right (i.e. 180° combined). During gallops, by contrast, the head always stabilized in all planes and the trunk rotates through several degrees (>20°) about the pitch axis.

The non human primate, more than any other, are restricted to an arboreal habitat. which are locomotor features associated with arboreal living. This paper presents a de-tailed analysis of Hanuman Langur positional behavior for all age-sex categories and during a complete range of behavioral contexts, following standardized positional mode. Chimpanzees, bonobos, mountain gorillas, and even lowland gorillas spend a relatively large amount of time on the ground, as reflected in their morphological adaptations for quadrupedal knuckle-walking. While Orangutans may have further refined their morphological adaptations to arboreal living since their split from the common ancestor, as the only great ape to retain a predominantly arboreal lifestyle, they are an important model in interpreting the shared morphological features of the great apes. Quantitative studies on the positional behavior of members of the Hominoidea are compared in order (1) to identify consistencies across the superfamily, (2) to contrast ape positional behavior with that of Old World monkeys (forest-living Papio anubis were chosen for study to reduce body size effects), and (3) to identify distinctive behaviors in each of the ape taxa. Differences in the way behaviors were sampled in the various studies necessitated considering posture and locomotion separately. 

MATERIALS AND METHODS

Study Animal: The Hanuman langur, (Semnopithecus entellus Dufresne ) is the most adaptable and widespread south Asian colobine non-human Primate of the Indian subcontinent. The species has been the subject of investigation because of its unique behaviour pattern including infanticide1-8. These langurs live in a wide range of habitats from the Himalayas and peninsular forests to semiarid woodlands, in villages and towns and in cultivated lands4,9. These animals are known for their remarkable adaptability, the species also has a highly variable social organization. The two basic types of social groups are bisexual troops and all-male bands. Troops are matrilineal groups of adult females and offsprings with either one adult male (unimale bisexual troop or harems) or more than one adult male (multi-male troops).
The percentage of one-male troops versus multi-male troops and the corresponding number of extra troop band males varies from site to site. Mostly, the reproductive units of the Jodhpur langurs are one-male bisexual troops. Mohnot et al.\textsuperscript{10} presented 11 years census data (i.e. 1968-78), Mohnot et al.\textsuperscript{11} carried out a 4 years demographic work (i.e. 1983-86). These studies enabled us to establish perspective and background of the study animal. Jodhpur is located in western Rajasthan (altitude about 241 m, Latitude 26° 18' N and longitude 73° 08 E) at the eastern edge of the Great Indian Desert. The town was erected on a hilly sandstone plateau of approximately 150 km\textsuperscript{2} surrounded by flat semi-desert. This diagonal plateau is inhabited by a geographically isolated pocket population of 1850-1900 langurs\textsuperscript{10}, which has been studied by various Indian and Foreign researchers for more than 40 years now. Langur exhibit clear-cut sexual dimorphism on average adult male weight 18.5 kg and female weight 12.5 kg.\textsuperscript{6} The number of bisexual troop varied between 28 and 32. The mean troop size is 38.5 members (range 7-120 members). The number of all male band is about 13; averaging 11.8 member (range 2-47 members).\textsuperscript{10-12} All male bands invade home range of bisexual troops is an unpredictable pattern, some time resulting in rapid or gradual replacement of the resident male.\textsuperscript{8}

The climate is dry, with maximum temperature about 48°C in May/June and minimum around 0° in December / January. Jodhpur used to receive its 90% scanty rainfall (average 360 mm) during the monsoon from July to September. The natural open scrub vegetation is dominated by xerophytic plants including \textit{Prosopis juliflora}, \textit{Acacia senegal}, \textit{Calotropis procera}, \textit{Caparis deciduas}, and \textit{Euphorbia caducifolia}. Water is available to all langur groups in this area. There are numerous irrigated parks and fields. The langurs feed upon about 200 natural and cultivated plants species available in the area. For religious reasons local people provision most of the groups here with wheat preparations, vegetables, fruits, nuts and even sweets. Some groups raid crops, but because they are considered to be sacred and never hunted (chasing by farmer/gardeners from their fields or park generally observed). Apart from feral dogs, there are no reports of natural predation. However, hyeana, wolves and jackals can be seen in this region.

The Langurs around Jodhpur are easy to observe since they are not to shy and are available on ground for longer daytime. After following some selective bisexual troops and all-male bands for 3-4 weeks, two bisexual troops and an all-male band will be taken as focal groups for the proposed study. First all the animals of focal groups will be individually identified by following them dawn to dusk for atleast 30-40 days. For data collection focal animal sampling scans and ad libitum sampling methods will be used.\textsuperscript{14}

\textbf{RESULTS AND DISCUSSION}

\textbf{Quadrupedal walks}

Quadrupedal walks are a type of symmetrical gait (i.e. equal timing between footfalls and handfalls) in which each limb is touching the support surface for more than 50% of the cycle time.\textsuperscript{15-16} The monkeys most commonly walked with a diagonal sequence footfall pattern that, following Hildebrand's definition, is characterized by a hind limb touchdown being followed by that of the opposite (contralateral) forelimb (Fig.1). Qualitatively, the trunk in hanuman langur remained in an essentially fixed horizontal position during walks. Only minimal pitch, yaw and roll rotations occurred in response to the sequential limb movements. Vertical linear displacements of the
head were also minimal. Head rotations, however, were variable. At times, the head would be held in a relatively static position, as when the monkeys focused gaze on the upcoming support surface and on a specific or distant target. At other times, by contrast, the head commonly rotated through several degrees about the pitch and yaw axes, as the monkeys visually scanned their physical surroundings.

When subjected to quantitative analysis, in hanumans walked slower, but with longer cycle durations, and experienced larger head and trunk rotational displacements about the pitch axis. Nevertheless, the basic kinematic pattern was comparable in this species, in that head rotations were greater than trunk rotations (Fig.2), and the mean pitch-plane rotational ranges of both segments were less than 20°. Note however, that whereas these rotations were always less than however, that whereas these rotations were always less than directly, often approached 180° as the Hanumans. Whereas the direction of rotation at times paralleled vertical displacements (i.e. head rise with upward rotation, head drop with downward rotation), this relatively inphase pattern was interrupted with periods during which vertical translation and rotation were nearly 180° out of phase. Out-of-phase periods occurred primarily near touchdown of a hand when the forelimbs were also nearly 180° out of phase and one hind limb was near midsupport.

The resultant whole-body deceleration, combined with decreased cranial trunk height, caused the head to pitch and drop downward. The head compensated for the downward pitch and drop, however, by rotating upward. This upward rotation, often anticipatory, peaked at or near maximal vertical descent. Occasionally, a downward compensatory head rotation also occurred near peaks in vertical ascent. Any particular association between vertical and angular head displacements could apparently be largely overridden voluntarily, however; as when the monkeys visually inspected their surroundings. In Hanuman langur head-to-trunk angles were more highly correlated with head-to-space angles verifying that the head was rotating on the trunk rather than the trunk on the head. All combined probabilities7 were significantly different at the 0.001 level17.

Gallops

Gallops differ from quadrupedal walks in that limb movements are asymmetrical (i.e. unequal timing between footfalls and handfalls), each limb is in contact with the support surface for less than 50% of the gait cycle time, and the cycle includes an airborne phase1,10,15. The Hanumans used two different types of gallops, as defined by Hildebrand18. In transverse gallops, touchdown of the leading hind limb the second hind limb to contact the support surface was followed by touchdown of the contralateral forelimb. In rotary or rotatory gallops, touchdown of the leading hind limb was followed by touchdown of the ipsilateral forelimb (Fig. 2). Qualitatively, the pattern of head and trunk movements during gallops was in marked contrast to the pattern during walks. Neither the head nor the trunk ever appeared to rotate about the roll or yaw axes. The trunk, however, made large rotations about the pitch axis that were necessary for the mechanics of gallops. Specifically, in the initial portion of the gait cycle, the cranial end of the trunk raised upward to lift the forelimbs and allow the feet to completely support body weight. Subsequently, the caudal end of the trunk rose upward to lift the hind limbs, while the cranial end dropped downward to lower the forelimbs, enabling the hands to completely support body weight. Finally, near the end of the cycle, the hands lifted off the support surface to allow a brief airborne phase as the caudal end of the trunk lowered once again to bring
the feet into contact with the support at the beginning of the next cycle. The head, in contrast to the trunk, rotated minimally about the pitch axis, but those rotations that did occur were usually in the same direction as the trunk. The head, however, did experience large vertical translations due to the rise and fall of the cranial end of the trunk. Near peak ascent or descent of the trunk, the head appeared to rotate downward or upward, respectively, suggesting an adjustment in head orientation.

During natural quadrupedal locomotion by free-ranging hanuman langurs either the head or the trunk remains stabilized rotationally relative to space (earth horizontal-gravity vertical), as defined in this study. During quadrupedal walks, the trunk is stabilized. Whereas the head can be stabilized, it frequently rotates through more than 20° about the pitch axis and up to 90° to the left or right (180° combined) about the yaw axis as the monkeys visually inspect their surroundings. During gallops, by contrast, the head is always stabilized in all planes whereas the trunk rotates through several degrees (>20°) about the pitch axis. Thus, during walks, the head rotates on a stabilized trunk, but during gallops, the trunk effectively rotates on a stabilized head. Mean head position in the pitch plane during both gaits closely aligns the horizontal semicircular canals with earth horizontal, and pitch rotations are symmetrical about that position. Comparisons between gaits and species Those measured variables that differ significantly between gaits can be attributed primarily to differences in the mechanics of walks and gallops. These variables include locomotor velocity, cycle duration and the characteristics of trunk pitch rotation required to achieve these velocities and durations. By contrast, those measured variables that are comparable between gaits are more likely to reflect morphological or physiological constraints or both. Tail kinematics because the leaf monkey species included in this study do not differ greatly in body size or available habitat type, our hypothesis was that they would not exhibit significant differences in tailposture or locomotor/positional behavior. Interestingly, kinematic analysis revealed that tail postures differ considerably among species. In all taxa, the tail inflection angle (Angle A) remained relatively constant throughout the stride cycle. langur exhibited a concave downward arch of the tail as reflected by positive tail inflection angles.

Mechanisms of segmental stabilization

Stabilization of the head or trunk or both can be attributed to the intrinsic mechanics of the musculoskeletal system (stiffness, viscoelasticity, joint design, segmental inertia) and the sensorimotor nervous system (reflexive and voluntary control). Studies attempting to flesh out the relative contributions of these variables have focused primarily on head stabilization. Kinematic and electromyographic studies of human head stabilization reveal that the relative contribution of mechanical versus neural mechanisms varies with the plane and frequency of head movement. For rotations in the yaw plane, voluntary control mechanisms dominate head stabilization at lower frequencies, whereas mechanical mechanisms dominate.

Segmental stabilization and spatial reference frames

Laboratory studies provide evidence that the body depends upon different segments (head, trunk, feet) to function as reference frames for supplying sensory information about spatial orientation. However, which segment provides the spatial coordinate system during a wide range of natural postural and locomotor activities with differing
segmental trajectories and velocities is unclear. The choice of reference frame apparently depends upon the segment being spatially oriented and the task requiring this orientation. The hind limbs (and forelimbs when quadrupedal), through tactile and proprioceptive inputs, can supply information about earth horizontal during quiet stance and small postural disturbances when physical contact with the support surface is continuous. During locomotion, by contrast, limb contact with the support surface is intermittent and often brief. Thus, the head and trunk segments are more likely to provide spatial reference frames during most locomotor activities.

**Head movements, gaze stabilization and vision**

The small head rotations that do occur about the pitch axis may serve to actively counter vertical body displacements in order to reduce the degree of eye rotation necessary for maintaining gaze on a fixed object or point in space. When human subjects focus gaze on a target while performing bipedal locomotor tasks, the head makes compensatory movements by rotating downward when it rises vertically, and rotating upward when it falls vertically.

**Neck**

The shortness of the neck in monkeys, combined with the technical limitations of filming wild animals under natural conditions, makes accurate kinematic analysis of this segment fall beyond the scope of the current protocol. The neck, forming the physical link between the head and trunk and containing essential somatosensory receptors, is nevertheless a significant segment in the mechanics and neural control of head and trunk movements. Thus far, head and trunk movements have been studied primarily in short-necked primates (monkeys, humans). Details of contributions by the neck to head and trunk movements during natural locomotion may be best revealed, however, through investigations of long-necked species (e.g. horses, giraffes).

**Fig1. Different positional Step in Hanuman langur**

**Fig 2. Different gallops positional Step in Hanuman langur**
ACKNOWLEDGEMENTS

The authors are grateful to Prof. S.M. Mohnot, Emeritus Professor of Zoology and chairman, Primate Research Center, Jodhpur for continuous encouragement, Prof. Devendra Mohan, Head, Department of Zoology, J.N.V. University, Jodhpur for facilities and logistic support during this study and to UGC, New Delhi for financial support under major project (No. F.34-460/2008 (SR) dt.02 Jan 2009).

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