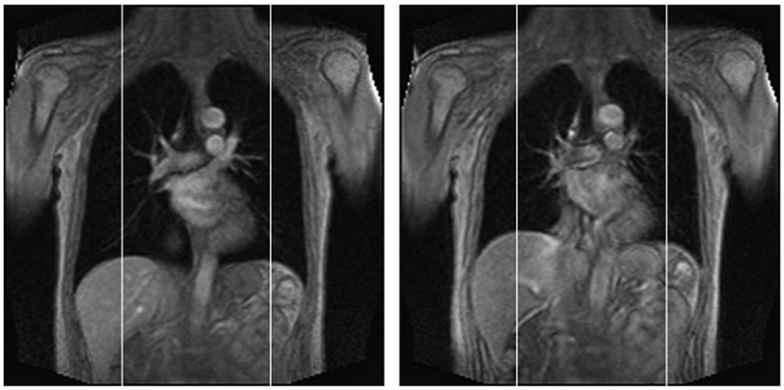

Fig. 1. 2D-MR images during singing at the beginning (left) and the end (right) of vocalization, on the frontal section at the center of the thorax at supine posture. White lines indicate sampling lines for measuring diaphragmatic motion.

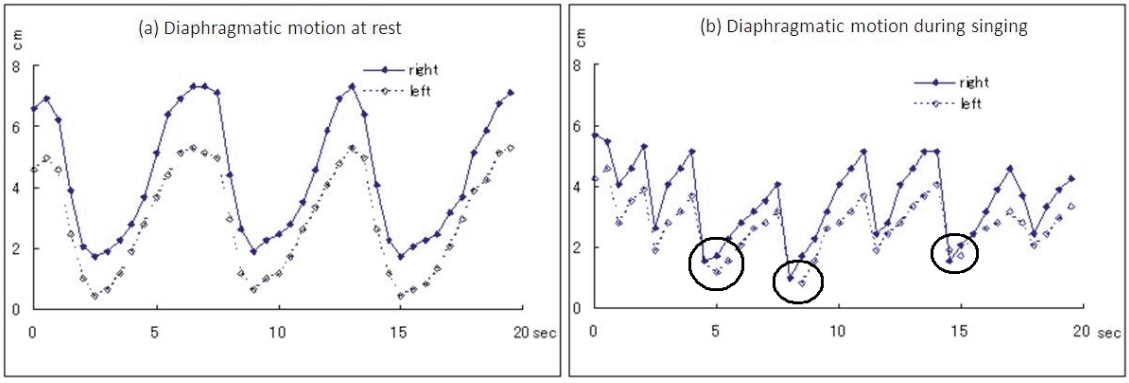

Fig. 2. Diaphragmatic motions at rest (left) and during singing (right). analyzed with dynamic 2D MR images. Intersecting points of sampling lines (white lines in Fig. 1) with the diaphragm were plotted at every 0.5 second.

of the diaphragm, respectively. When the diaphragm is shifted downward, inspiration occurs. Then the diaphragm gradually elevates during expiration. At rest without vocalization (left panel in Fig. 2), bilateral diaphragmatic motions were completely synchronized. Although the left diaphragm was always lower than the right diaphragm with approximately 2 cm difference, the motion was nearly symmetric. On the other hand, paradoxical movements in the left diaphragm were observed during singing. At the beginnings of the third, fourth, and sixth vocalization periods (circles in the right panel in Fig. 2), the left diaphragm further shifted downward in spite that the right diaphragm began to elevate.

4. Discussions

Our experiment indicates that there is apparent asymmetry in the diaphragmatic motion at the beginning of vocalization. Since abdominal muscles work during vocalization, this motion asymmetry is thought to be due to the difference of mechanical transmission of the abdominal muscle power. Through the solid liver, abdominal muscle contraction during vocalization is precisely transmitted to the right lung. On the other hand, it is often incorrectly transmitted to the left lung at the beginning of vocalization due to highly deformable stomach. In addition, the diaphragmatic motion asymmetry does not occur during resting breath because the abdominal muscles do not participate.

Although the experiment was done only under supine posture due to technical limitation, observed phenomenon is thought to be common to all body postures. Recent linguistic research has suggested the origin of syntax may be segmentation of continuous song notes (Suge and Okanoya, 2010). Segmentation of vocalization is to stop and to restart immediately expiratory airflow under cooperative activities of expiratory muscles and acoustic source organs. It is known that affective fibers in the vagal nerve are distributed on the pleura and sense their mechanical distensibilities. Mechanical information of the right pleura is thought to be preferentially included in the speech circuit in order to realize precise control of expiratory airflow.

FOXP2 (forkhead box P2) is so far the only gene implicated in Mendelian forms of human speech and language dysfunction (Lai *et al.*, 2001). A point mutation in *FOXP2* co-segregates with a disorder in a family in which half of the members have severe articulation difficulties accompanied by linguistic and grammatical impairment. The human *FOXP2* protein differs from the gorilla and chimp protein at just two residues, and is shared with Neandeltls (Klause *et al.*, 2007). Knock out experiments revealed that loss of *FOXP2* in mice leads to defective postnatal lung alveolarization as well as brain development disorder (Shu *et al.*, 2007). Comparison between the chimpanzee and the human has revealed that the two human-specific amino acids alter *FOXP2* function by conferring differential transcrip-