



Fig. 4. Signals obtained from implemented cECG monitoring system from a subject. (a) Engine off. (b) Engine on.

Table 1. Summary of Se, P+, and RMSE during the engine off and on.

Subject #	Age	BMI	Se (%)		P+(%)		RMSE	
			Engine OFF	Engine ON	Engine OFF	Engine ON	Engine OFF	Engine ON
1	23	19.5	100	100	100	100	1.8	30.6
2	27	28.6	99.0	100	100	100	1.3	7.8
3	26	19.0	100	98.9	100	100	2.2	2.3
4	33	19.5	100	100	100	100	0.6	0.8
5	24	16.7	100	100	100	100	1.0	14.9
Average	26.6	20.66	99.8	99.8	100	100	1.4	11.3

(Fig. 3(b)). During the test, subjects kept still on the seat for 60 seconds with 1 shirt. The material and thickness of the shirt was not identified.

## 5. Result and Discussion

Figure 4 shows an example of the signals obtained from a subject. Though noise contaminated into the signal during the engine on compared with the situation engine off, R-waves are visible and it is clear enough to detect its' peaks. Quality figure of R-wave detection algorithm is given by Detection Sensitivity (Se) and Positive Predictivity (P+):

$$Se = TP / (TP + FN) \times 100\%,$$

$$P+ = TP / (TP + FP) \times 100\%,$$

where  $TP$  stands for true positives, which is the total number of peaks correctly detected by the detector.  $FN$  and  $FP$  denoted as false negative and false positive, respectively. The RRI detection performance analysis metric, which is used for the validation of the test result, is the root mean square errors (RMSE) between the reference signals. The algorithm is tested on 60 seconds ECG data for each subject, which obtained from cECG system. Table 1 tabulates the test results of R-wave detection for cECG measuring.

Overall averages of Se and P+ during the engine off were 99.8% and 100%, and the engine on were 99.8% and 100%, respectively. Although RMSE increased during engine on compared with when it is off, the average is 11.3 ms. The sampling rate of commercial heart rate variability instruments varies from 128 to 1000 Hz [12]. The accuracy of QRS detection is 8 ms in case the sampling frequency is 128 Hz. The 11 ms RMSE is only a little larger than the 8 ms which is the sampling rate of heart rate variability instruments. It is considered that the detection accuracy is acceptable for HRV analysis. The proposed system is prospective for practical use from the point that these results are obtained from the subjects who had wide range of BMI, 16.7 to 28.6 kg/m<sup>2</sup>, and different materials and thickness of the wearing shirt.

## 6. Conclusion

Sufficient results, Se of 99.8% and P+ of 100% with low RMSE of 11.3 ms were obtained from 5 subjects in the situation of engine on with an actual car. The flexible active electrode with neutralization circuit, AC coupling, DRL circuit, and digital filtering by DSP helped to reduce noise as well as signal attenuation. As further studies, it needs to be tested in driving scenes. Road vibrations, steering, pedal-