Eur Arch Otorhinolaryngol
DOI 10.1007/s00405-014-3194-0

RHINOLOGY

Mental distress and effort to engage an image-guided navigation system in the surgical training of endoscopic sinus surgery: a prospective, randomised clinical trial

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Received: 30 May 2014 / Accepted: 1 July 2014

Abstract The use of image-guided navigation systems in the training of FESS is discussed controversy. Many experienced sinus surgeons report a better spatial orientation and an improved situational awareness intraoperatively. But many fear that the navigation system could be a disadvantage in the surgical training because of a higher mental demand and a possible loss of surgical skills. This clinical field study investigates mental and physical demands during transnasal surgery with and without the aid of a navigation system at an early stage in FESS training. Thirty-two endonasal sinus surgeries done by eight different trainee surgeons were included. After randomization, one side of each patient was operated by use of a navigation system, the other side without. During the whole surgery, the surgeons were connected to a biofeedback device measuring the heart rate, the heart rate variability, the respiratory frequency and the masticator EMG. Stress situations could be identified by an increase of the heart rate frequency and a decrease of the heart rate variability. The mental workload during a FESS procedure is high compared to the baseline before and after surgery. The mental workload level when using the navigation did not significantly differ from the side without using the navigation. Residents with more than 30 FESS procedures already done, showed a slightly decreased mental workload when using the navigation. An additional workload shift toward the navigation system could not be observed in any surgeon. Remarkable other stressors could be identified during this study: the behavior of the supervisor or the use of the 45° endoscope, other colleagues or students entering the theatre, poor vision due to bleeding and the preoperative waiting when measuring the baseline. The mental load of young surgeons in FESS surgery is tremendous. The application of a navigation system did not cause a higher mental workload or distress. The device showed a positive effort to engage for the trainees with more than 30 FESS procedures done. In this subgroup it even leads to decreased mental workload.

Keywords Heart rate variability · Navigation · FESS · Surgical training · Mental workload

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Introduction

The clinical use of the navigation system in functional endoscopic sinus surgery (FESS) procedures varies strongly among hospitals. In some institutions the system is only used under complicated conditions, whereas in other hospitals the navigation system is part of the daily routine [1].

Experienced surgeons report a better intraoperative orientation, an improved situational awareness and a decreased surgical risk with the use of the navigation system [2]. Although experts fear that the usage of the navigation system during training would lead to a loss of surgical skills and anatomical knowledge [3], those who use the navigation system, support its usage also for simple procedures on a daily basis. This is because a familiarity with the system has to be achieved for the best performance and the best patient results. However, the correct usage of these devices needs proper and regular training. Otherwise, these systems lead to more stress than real help for the surgeon. The usage and the evaluation of the navigation system in the surgical training have been rarely evaluated.

In this context, the present study examines three cardiovascular parameters during the FESS surgery: the heart rate (HR), the respiratory frequency and the heart rate variability (HRV). Additionally, the left masticator tone was monitored to measure a certain teeth clenching. Actually, this study is the first field study in literature, which measures the heart rate variability in FESS surgery continuously. These well-established biometrical parameters are frequently used in research of mental and physical workload [4–10].

The heart rate is frequently used for the detection of mental workload because of the easy determination through the electrocardiogram. The heart rate increases with an increase of mental effort [11].

Unfortunately, the heart rate is influenced by external factors like emotions and muscle work [7]. Nevertheless, the heart rate is used in many studies as a parameter of mental effort, although the quantity of physical or emotional factors cannot precisely be identified [10, 12].

The HRV describes the variability of the single heart beats to each other. The physiological condition in rest situations shows a high heart rate variability because of the high influence of the parasympathetic nerve system. A relaxed and healthy heart does not beat regularly but slightly irregularly. In other words, the distance between two heart beats (two R-waves) is varying. The HRV can be calculated by these interbeat intervals. Kalsbeek and Ettema proved in their studies that the HRV decreases by doing binary cognitive tasks. In other words, the heart beats more regularly in situations with high mental workload [13–15]. Meanwhile, the HRV is an often used parameter for quantification of mental load. It is used for example by pilots to quantificate the efficiency of training and stress levels during flights [4]. However, heart rate variability is a complex biosignal influenced by many factors beyond the mental distress and the psychical demand [16]. For its proper evaluation, a spectral analysis is needed to divide this parameter in its different elements.

The physical and mental stress during functional endoscopic sinus surgery (FESS) is without doubt high [17]. Thus, the aim of this study is to objectively record the mental workload and distress of surgeons in training during a standard FESS procedure with and without the use of a navigation system.

The following questions should be answered:

- Which situations create the highest stress levels for the trainee surgeons?
- Does a navigation system cause an increase in mental effort and distress compared to the classic FESS?
- Is the navigation system suitable for the surgical training or is the effort to engage too high?

Materials and methods

In this randomized prospective clinical study, eight trainee surgeons performed FESS surgery under supervision of two experienced rhinosurgeons on four patients each. In summary 32 patients participated. The participating surgeons had different level of experience in the FESS surgery. Half of the surgeons had already done more than 30 conventional FESS in the past and belong, in this way, to the more experienced group. The other 4 surgeons with less than 30 FESS form the less experienced group. The cut off was set by 30 FESS procedures (median). In all operations a navigation system was actually not necessary. No complicated anatomical or revision cases were included. During the operation, as well as 5 min before and after, the surgeons were connected to the biofeedback device (NeXus 10, Mindmedia, NL). The heart frequency, the respiratory frequency and the masseter tone were measured continuously. The different parts of the surgery (e.g. opening the different sinuses, changing the angled endoscopes) and critical events (e.g. stronger bleeding or overtaking the surgery by the supervisor) were marked by a manual trigger of the biofeedback device.

The allocation to the study groups was determined through a block randomization. One side of the patient was operated with the aid of a navigation system, the other side without.

Navigation

In this study two identical navigation systems were used: The VectorVision compact® with laser registration (BrainLAB, Feldkirchen, Germany). The OR-team (except for the trainee) was very familiar with this system through prior studies [18–20].

Heart rate variability analysis

In the spectral analysis of the HRV three frequency bands are important:

Very low frequency: 0.02–0.06 Hz
Low frequency: 0.07–0.14 Hz
High frequency: 0.15–0.40 Hz

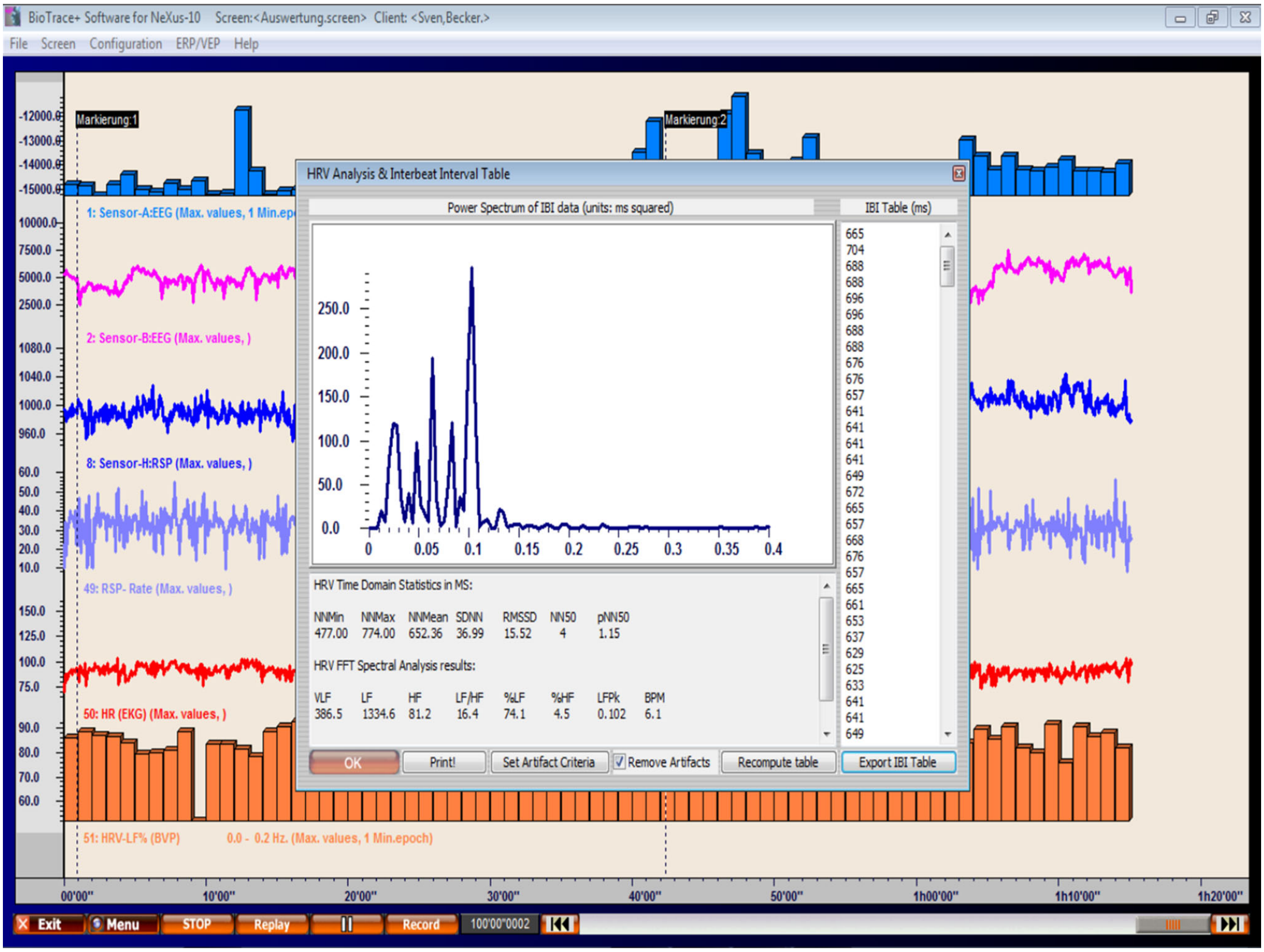


Fig. 1 Screenshot of the intraoperative biofeedback measurements with MindMediás BioTrace+ Software. The spectral analysis shows high values in the 0.1 Hz frequency as a sign of mental relaxation before surgery

In the very low frequency band the temperature changes are dominating. In the low frequency band the blood pressure and adrenaline uptake are involved, and in the high frequency band the respiration frequency. The respiration frequency is a possible source of artifacts (speaking, moving). It was measured in this study for the right interpretation of the low and high frequency band [21.]

All three frequencies show a suppression of the HRV by physical and mental effort [15]. The strongest difference is seen in the low frequency band, especially in the 0.1 Hz component [22]. The 0.1 Hz component is the main parameter for the registration of mental effort in this clinical trial.

The identification of the R-waves in the ECG was carried out by Biotrace software of the biofeedback device (Fig. 1). The resulting time series were analyzed by CARSPAN software (developed by B. Mulder, Groningen). The spectral analysis allows a quantification of the HRV. CARSPAN uses the fast Fourier analysis to split the time series into spectra. CARSPAN splits the deviations of the mean in several frequencies. During mental or physical effort the heartbeat becomes more regular to ensure a continuous oxygen supply of the brain. Thereby, the deviations of the mean become smaller, because they are more regular. The lower the power of the HRV, the more demanding the task is.

Masseter tone and heart rate analysis

During each operation, the masseter tone and the heart rate were measured as additional indicators of physical [23] and mental [8] effort. In situations of high mental effort a higher heart rate and a significantly higher masseter tone were measurable [24].

Statistics

In the statistical analysis of this study a team of the institute for biometry was involved.

Each surgeon performed four operations to cover all four of the following possibilities:

- Begin with the right side, without navigation
- Begin with the left side, without navigation
- Begin with the right side, with navigation
- Begin with the left side, with navigation

For the statistical evaluation an analysis of variance (ANOVA) for repeated measurements (within-design) was performed. The program used was SPSS 15.0. A significance was considered if $p < 0.05$. The effect size η^2 was also calculated.

Results

Patient's collective

Four subjects (surgeons in training) were male, four female and all were right-handed. The average age of the surgeons was 31 years (between 27 and 33). All 32 patients were included. The average age of the patients was 46 (SD 9.5) years.

The indications for the paranasal sinus operations in this study were:

Bilateral chronical sinusitis $n = 32$

Bilateral polyposis of the ehtmoid bone $n = 17$

Additional septum deviation $n = 16$

Polyposis nasi, asthma and aspirin intolerance (sampter trias) $n = 3$

In all patients all landmarks were visible with preoperative endoscopy and CT scan.

Dropouts

All surgeons participated in this study performed all their operations. The included patients also participated without dropouts. Two operations had to be removed from the analysis because of an intraoperative system failure of the navigation device. The whole operation was then performed without navigation.

Analysis of cardiovacular parameters (heart rate, heart rate variability, masseter tonus)

The heart rate was significantly higher during surgery, compared to the HR before and after the surgery (baselines). Preoperatively, the heart rate of the subjects was at physiological resting levels (in average 92 beats/min). During the surgery, the heart rate increased significantly (in average 98 beats/min) and decreased after the surgery again. These findings correlated with the surgeons' concentration level and mental distress situation: Before the procedure the surgeons were relaxed. To fulfill the surgery a higher mental effort was necessary. No significant difference of mental effort was visible with the use of the navigation system ($p = 0.569$, $\eta^2 = 0.048$). Both parts of the operation—the navigation-supported part as well as the non-supported part showed the same heart rate levels (Fig. 2).

A corresponding mirror-inverted result was visible in the heart rate analysis. The HRV was higher in the preoperative section in comparison to the intraoperative HRV, which was low, suitable to the higher mental effort, the physical demand and the distress level. No significant difference was registered between the two parts of the surgery (with and without navigation system). On the contrary, in the non-supported part of the procedure a slightly lower HRV was seen compared to the navigation-supported side (Fig. 3). This result may not be significant with $p = 0.131$ but the effect size of 27.3 % is very high, and speaks for a certain validity.

After the operation some time is required to reach the preoperative HRV level (resting level). An additional mental load with the use of the navigation system could not be observed.

However, a more detailed inspection of the data revealed a difference in psychical distress situation among the eight participating surgeons. In both subgroups (with >30 FESS procedures done, as well as <30 FESS procedures) high heart rate levels and low HRV levels during FESS surgery are visible. However, as it becomes evident from Fig. 4 the HRV of the more experienced group was higher in both parts of the surgery. The HR was accordingly lower in comparison to the less experienced subgroup with less than 30 FESS procedures (Fig. 5). In other words

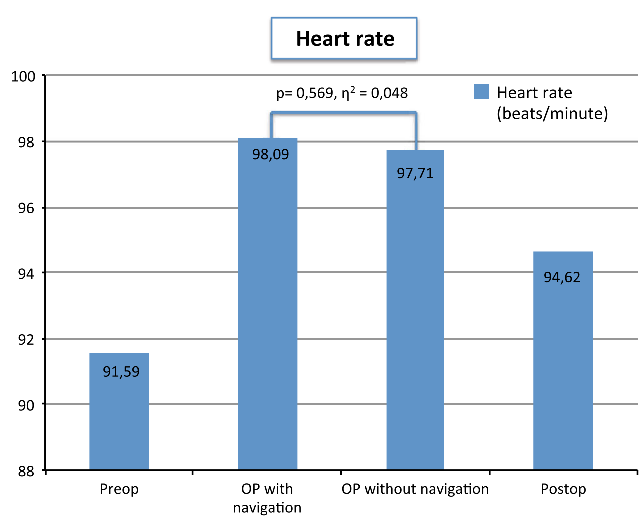


Fig. 2 Heart rate (HR) of the surgeon before and after the surgery and in the two study groups

in the “experienced” subgroup a decreased stress level compared to the “beginner” group could be observed.

None of the two groups showed a difference in the mental workload and the distress level between the navigation-supported part and the non-supported part.

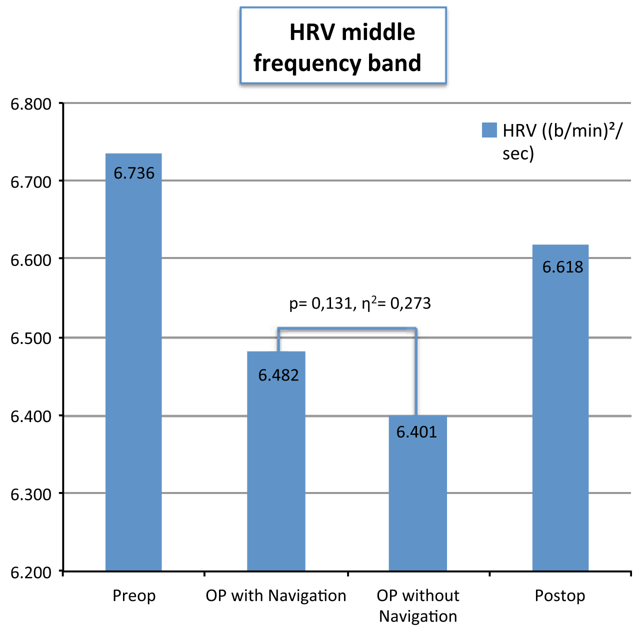


Fig. 3 Heart rate variability (HRV) of the surgeon before and after the surgery and in the two study groups

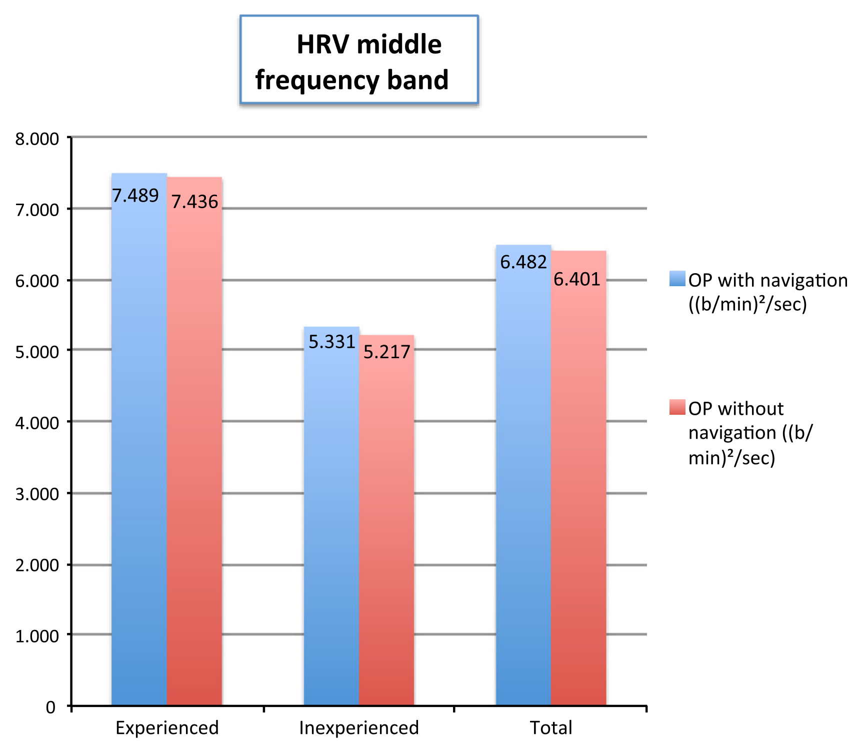
According to the objective (HRV, HR and Masseter tone) data the following intraoperative stress situations could be identified:

The less experienced surgeons (<30 FESS) got distressed by a short absence or diversion of the supervisor, the procedure of septoplasty and the switch to the 45° angled endoscope. No higher stress levels were monitored by operating near risk structures like the skull base or poor vision in this group. The more experienced surgeons (>30 FESS) got distressed by other colleagues or students entering the theatre as well as by operating near the skull base. They also got distressed during the preoperative waiting for the measurement of the baseline due to the permanent time pressure in the hospital as well as poor vision due to insufficient bleeding control (Fig. 6). Difficult maneuvers during the operation or the use of the 45° endoscope did not lead to a higher masseter tonus or a lower HRV in this group.

Discussion

This clinical trial provides insights into the trainee surgeons’ mental distress situation and effort during a FESS procedure with and without navigation support. The heart rate and the HRV are cardiovascular parameters with a high significance for the detection of psychic and mental effort [5, 16, 25, 26].

Fig. 4 The difference in the middle frequency band between the less (<30 FESS) and the more experienced (>30 FES) surgeons in training. The surgery with and without navigation is compared



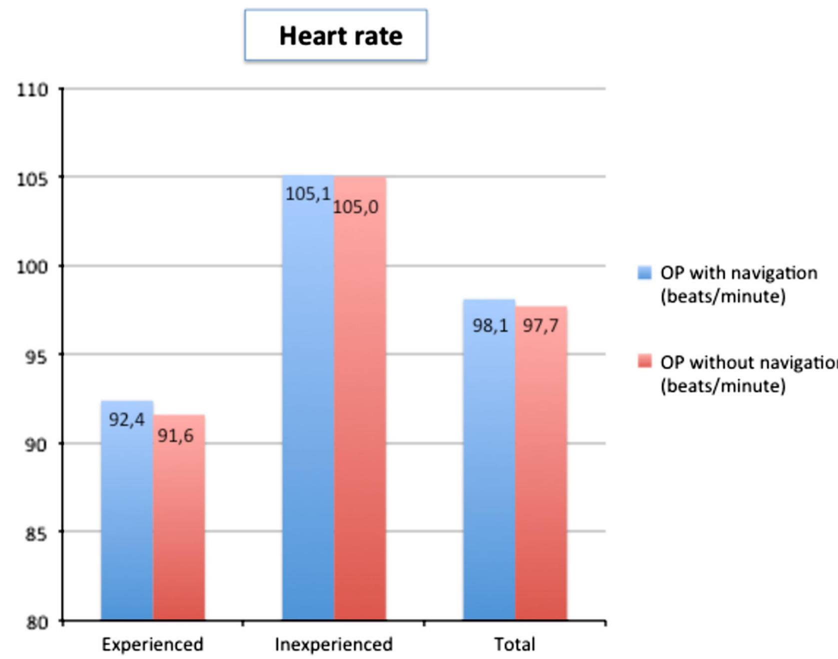


Fig. 5 The difference of heart rate between the more experienced (>30 FESS) and the less experienced (<30 FESS) surgeons in training. The surgery with and without navigation is compared

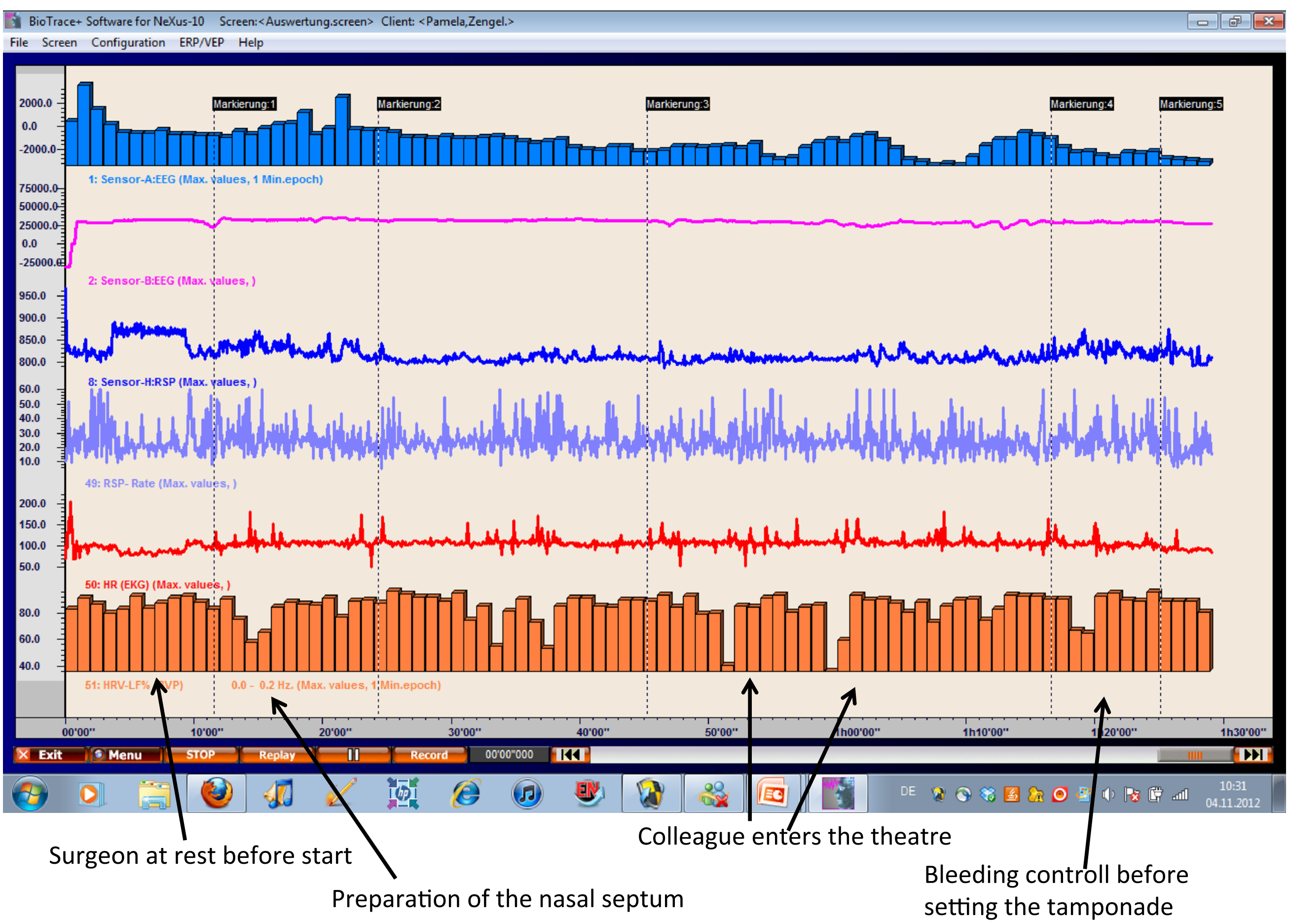


Fig. 6 Screenshot of the intraoperative biofeedback measurements. The masseter tone (*blue bars*) is decreasing during surgery. The *second* and *third line* constitutes the raw data of the ECG and the respiration. The *red line* represents the heart rate in beats per min. The *last row* demonstrates the fluctuations of the middle frequency band, which is calculated through the intervals between the R-hulls in the ECG (interpeak values). The *arrows* point to certain situations where the power of the middle frequency band decreases (high mental effort)

The spectral analysis can separate the HRV into the three components mentioned before, which can be analyzed and be considered separately [4]. The suppression of the HRV in situations of mental effort is visible in all three frequency bands. But the biggest difference is seen in the low frequency band [21]. Another reason why this band is to be preferred, is that in studies with short acquisition times, like this study, the 0.1 Hz band is the most sensitive one [21]. Respiratory rate changes too slow for a real time acquisition. Nevertheless, the difficulty is that many different activities and situations can lead to an increase of psychic demand and there is no better scientific method for an objective evaluation yet. Neither is there currently an objective method for the quantitative measurement of the psychic demand. The only way is to indirectly evaluate this phenomenon from some parameters such as the HR, HRV or masseter tonus, as we did in this study.

Two different aspects were considered: (1) A comparison of the mental workload and psychic demand during a navigation-supported and a non-supported FESS procedure. (2) Evaluation of other factors, which lead to a surgeon's increased psychic distress level.

The HRV was measured continuously during the whole operation, and 5 min before and afterwards for baseline measurements. Our baseline is defined as a situation at rest but in the same environment. The baseline is chosen consciously as the time before and after surgery in the operating theatre and not on a free day without operating procedures like in other studies [17]. The intention is to create similar circumstances as during the surgery (i.e. oxygen-saturation, temperature, daytime) [10]. The results of this study emphasize that high mental load dominates in surgical interventions like FESS procedures. During both procedures, with and without navigation device, the stress levels were significantly higher, than before or after the operations. Preoperatively, the HRV is high, during the operation the HRV is suppressed by the influence of the sympathic nerval system. After the operation the HRV increases again.

There was no significant difference detectable in the HRV levels with the application of the navigation system compared to the non-supported classical FESS side, which means the stress level was almost equal on both sides. Nevertheless, the HRV was slightly higher in the navigation-supported part of the procedure. This result is with $p = 0.131$ not significant but the effect size of 27.3 % is very high. We can suppose that in a study with a bigger number of cases, a significant result could be achieved. In other words, with a bigger case number maybe significant lower stress levels with the usage of navigation system can be shown.

A mirror-inverted picture to the HRV is visible with the HR analysis.

After categorizing the surgeons to their level of experience, a different picture emerged: The more experienced group (>30 FESS procedures) showed in both parts of the surgery (with the use of the navigation system and without) a higher HRV and lower heart rate levels. That means a lower mental workload and distress level than the colleagues with less than 30 FESS procedures done. Therefore, we can suppose that the mental workload and psychic demand decrease by the increasing level of experience. In both groups no difference in stress levels between the navigation-supported part and the non-supported part was measurable.

However, we have to consider that the distribution of the single distress factors during the surgery could have changed without changing the overall mental workload, meaning a "workload shift". Manzey et al. describe that the effort and the distress level benefit clearly from the usage of a navigation system in experienced rhinosurgeons. However, the mental demand can increase because of handling an additional integrated technical device.

In this trial a very important aspect was to fulfill this procedure without any time pressure, in an environment familiar to the surgeons and after a systematic supervised instruction. The surgeons reported even a mental relief with the use of the navigation system and the new technology as motivating and not frustrating [13]. Hence, we cannot observe a workload shift toward the navigation.

Furthermore, some other distress factors attracted attention independently from the usage of the navigation system. A significant depression of the HRV of the younger surgeons in training could be monitored by a short absence of the supervisor, the procedure of septoplasty and the switch to the 45° endoscope. The more experienced surgeons in training were distressed by bleeding situations with poor vision. A reason for the higher distress by the presence of other colleagues and students in the theatre could be the developing concurrence between the trainees and the psychosocial pressure in an university clinic.

To our surprise, risk structures like the skull base or bleeding and poor vision did not increase the mental workload of the less experienced surgeons as much as expected. This could be explained by the fact that the surgeons knew they were under supervision, and in a risk situation the supervisor would support them and would take over the procedure. This result is compatible with the findings of the subjective questionnaire of the first part of this study [13].

A question to be discussed is whether the higher workload and psychic demand during the surgeries have negative consequences on the patient's outcome and the long-term health of the participating surgeons. During an operation, a certain degree of psychic distress is desirable because it goes with increased concentration and situation awareness. Especially, for risk structures and the usage of angled endoscopes an increased level of concentration is necessary. Therefore, in the surgical training an increased mental workload is to be rated as physiological "eustress" [26], and is not a harmful "distress" [27]. "Distress" can typically lead to overload and burn out syndromes. The line between "eustress" and "distress" is not clearly definable. Therefore, avoidable stressors like the presence of colleagues in the operating theatre or the simultaneous teaching of students should be eradicated. Because of these findings student teaching in the theatres of our department is not performed any more by the operating surgeon but by an uninvolved supervisor.

Further investigations

An interesting question for further investigations would be the detection of mental effort and distress level of experienced surgeons during supervision of surgeons in training doing a FESS procedure. An aircraft study showed corresponding high distress level of the captain during a flight of a pilot in training [4]. The pilot in training as well as the captain had similar distress levels in the same situations (e.g. gear down). Because of the high responsibility and the continuous preparation for intervention the high mental effort is comprehensible. The powerless feeling of being dependent from the correct reaction of another individual can be a factor of great distress. This situation could lead in the future to an overload even to a burn out syndrome. The same situation is likely to exist for supervisors in FESS surgeries. An open talk about confidence, team work and limits can help here.

Conclusion

Endoscopic sinus surgery comes along with high mental workload for surgeons in training. In such situation some stress reactions are physiological, natural and necessary to achieve a better situation awareness. However, too much stress and on a permanent basis, is unphysiological and can tire out and frustrate the surgeon. Therefore, avoidable stressors have to be identified and then try to be avoided.

The navigation surgery is connected with a higher organizational effort, but the trainee surgeons are thankful for this opportunity. The additional information of the system is seen by the surgeons as a support and do not lead to a higher mental distress level in comparison to the standard FESS. The handling of a new device and the additional software do not lead to a higher mental demand or worse outcome.

However, handling the navigation system has to be practiced. The right usage of the device, the software, as well as the registration and the reasonable application has to be learned. Training and high situation awareness is needed. The handling of a navigation system does not lead to a higher stress level during FESS. There are more external factors, which create disturbances. Therefore, surgical training should take place in a familiar environment, and without time pressure. Only this way it can be ensured that the surgeon is concentrated and can work without additional pressure and mental distress. In this study, the participants could process and correctly classify the presented information most of the time. However, this would not be possible without a correct and sufficient training in the anatomy of the paranasal sinuses.

In situations where the navigation is mandatory (e.g. missing landmarks) it can only be used effectively and correctly by regular training and a sufficient experience with the device.

Conflict of interest All authors state that there is no conflict of interest.

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