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Subjective workload measurement of the transition from a conventional operative microscope to a Robotic Digital Microscope. A pilot study

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1. Introduction

The optical magnification of the intraoperative microscopes revealed another dimension in our understanding of neuroanatomy, enabling better visualization, dissection and protection of the neural structures while operating on various pathologies. The operative microscope has established as a pillar of surgical precision and defined a completely new era in neurosurgery – the microneurosurgical era.

A new class of intraoperative visualization tools, the operative exoscopes, has been introduced recently. They have proven to have some important advantages, like better magnification, brightness, mobility, compared to the conventional operative microscope (Fiani et al., 2021; Hafez et al., 2021; Herlan et al., 2019; Langer et al., 2020; Maurer et al., 2021; Nishiyama, 2017). Moreover, the exoscope brings better ergonomics to the neurosurgical operating theatre, which is considered as a great asset given the fact that work-related musculoskeletal disorders (WMSD) are becoming widespread in the neurosurgical society (Hafez et al., 2021; Lavé et al., 2020; Maurer et al., 2021). WMSD have proven negative impact on the surgical performance and decrease the surgeons' quality of life (Gadjradj et al., 2020; Lavé et al., 2020). The operative exoscope could play a substantial role for the resolution of these problems of ergonomics by reducing the continuous neck flexion and uncomfortable position of the neurosurgeon. In a comparative study 84% of the participants found the exoscope more ergonomic than the OPMI (Maurer et al., 2021).

The substitution of a well-established, essential tool with longstanding traditions, proven qualities, and continuous technological development like the operative microscope, with a new one, with a completely different concept and modus operandi, could be challenging for the neurosurgeon. Some studies point out the presence of a learning curve that is still unknown (Hafez et al., 2021; Visocchi et al., 2020a, 2020b).

The purpose of the present pilot study is to evaluate the subjective workload for transition of a single experienced neurosurgeon from a conventional operative microscope /OPMI/ to a Robotic Digital Microscope /RDM/ measured by the NASA Task Load Index (NASA-TLX).

2. Materials and methods

For the period 01.04.2021–01.06.2021 at the Department of Neurosurgery of the University Hospital "N. I. Pirogov", Sofia, Bulgaria 41 consecutive patients (23 female and 18 male) were operated on using the Aesculap AEOS® Robotic Digital Microscope. Sixteen of the operations were cranial and 25 spinal. NASA-TLX questionnaire /Fig. 1 /was filled in after each operation by the operating neurosurgeon/ N.G./. The NASA-TLX score was used to assess the subjective workload of a single experienced neurosurgeon while using the AEOS® Robotic Digital Microscope in our center. The result from the NASA-TLX was used to outline the learning curve of the transition of an experienced neurosurgeon from OPMI to a RDM. NASA-TLX has already been approved as a valuable tool for evaluating the learning curve in a few studies for laparoscopic general surgery, but so far never in neurosurgery (Auerbach et al., 2011; Mohamed et al., 2014). A weighted NASA-TLX score was calculated by the NASA-TLX application with weight assigned to each index criterion. The less important the criterion, the smaller the weight assigned to it. We made an individual weighting of the subscales of NASA-TLX following the objectives of our study as follow: **Mental Demand** – 1, **Physical Demand** – 1, **Temporal Demand** – 2, **Performance** – 4, **Effort** – 3, **Frustration** – 4. Our arguments were that Performance and Frustration are the most important subscales in our subjective workload measurement for the transition from an established method of intraoperative visualization to a new one. The Performance is weighted with 4, this is the most important criterion – the best result possible should be sought in every single case. The same weight, 4, we assigned to Frustration. Effort was weighted with 3 as the purpose of the RDM is to reduce the effort for the operator during the surgical procedure (see Fig. 2).

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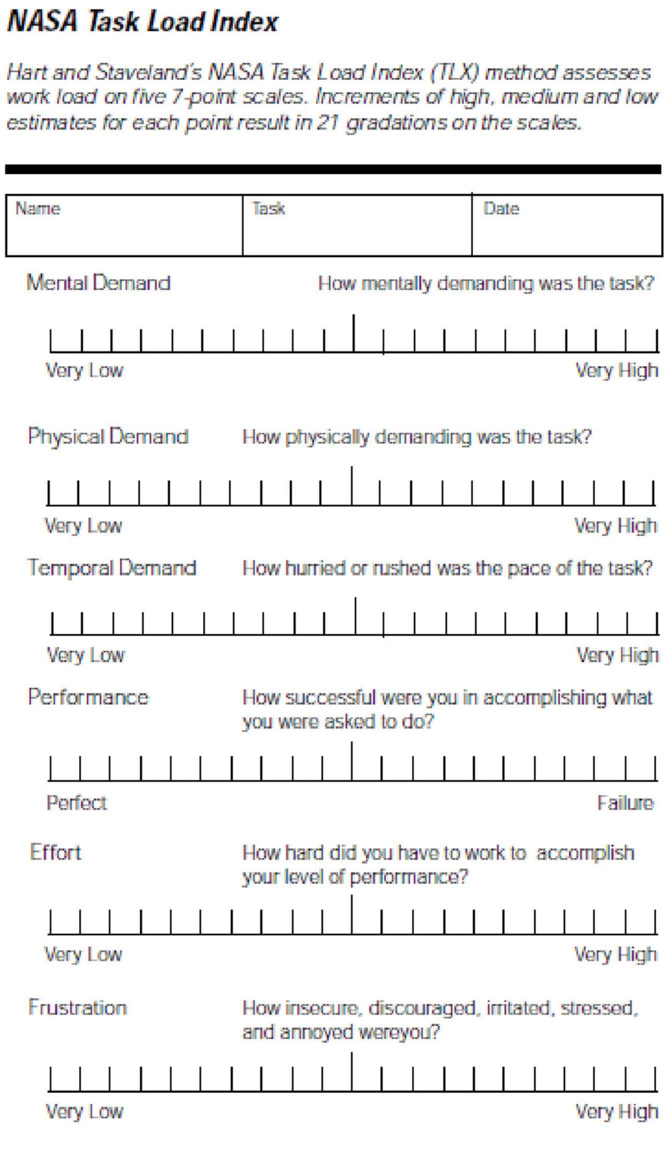

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

Fig. 1. NASA Task Load Index (NASA-TLX) questionnaire that was filled after each operation.

3. Results

Forty-one operations were conducted in the study by a single experienced neurosurgeon /N.G./– 16 cranial /Table 1/ and 25 spinal /Table 2/. The cranial operations were in the field of neuro-oncology – glial tumors, meningiomas, brain metastases, one pituitary adenoma and one hemangioblastoma. The spinal operations were more and comprised a much greater variety – from minimally invasive procedures like microdiscectomy, spinal decompressions, trauma cases and spondylolisthesis to complex intramedullary tumors. Stratifying the operations by their complexity was outside the scope of this study and brings little impact on the current pilot study. The NASA weighted rating gradually decreased /Fig. 3/. In our study a cut-off result was decided to be the NASA weighted rating of 33–34, which was the sum of the scores for high performance, low effort, low frustration and high overall operator's satisfaction.

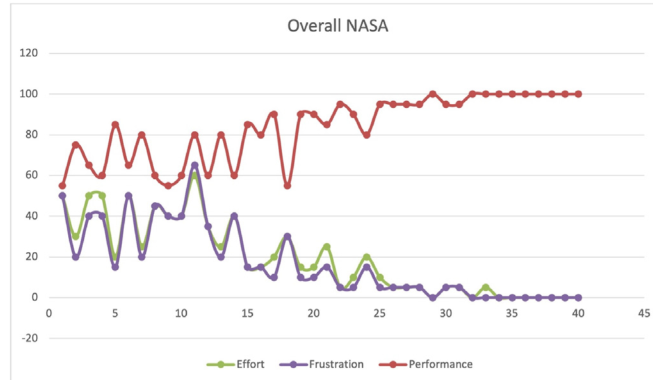

Fig. 2. Overall NASA-TLX score for the 41 operations conducted at the Department of Neurosurgery with the Aesculap AEOS® Robotic Digital Microscope. The dynamic changes of the 3 major criteria from the NASA-TLX score/ Effort (green line), Frustration (purple line) and Performance (red line)/ are presented above. Our chart shows that the operative effort and frustration decrease over time while performance is enhanced. Consistently high overall result is achieved after the 20th operation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

The operative microscope has established as mandatory in the everyday neurosurgical practice. A new class of tools for intraoperative visualization and magnification, the Robotic Digital Microscope like an example of the exoscopes, have been proposed as an alternative to the well-established neurosurgical operative microscope (Nishiyama, 2017). In some surgical fields there have been attempts to replace the OPMI with 3D digital microscopes or exoscopes (Crosetti et al., 2020; Piatkowski et al., 2018). There are some case reports and small case series of the use of 3D exoscopes mainly in spinal surgery (Beez et al., 2018; Siller et al., 2020).

The RDM has been shown to be comparable to the conventional OPMI first in cadaver and animal studies (Hafez et al., 2021; Herlan et al., 2019; Mamelak et al., 2008). On many characteristics concerning image quality exoscopes are equivalent to OPMI and when combined with a 4K high-definition screen exoscopes are even better (Langer et al., 2020; Ricciardi et al., 2019b; Visocchi et al., 2020a, 2020b). When working in deep locations the magnification and visual quality is considered better when using the exoscope (Fiani et al., 2021; Hafez et al., 2021; Krishnan et al., 2017; Visocchi et al., 2020a, 2020b). The wide screen, visible to everyone in the operating theater, allows for good coordination between the operating surgeons, the assisting nursing staff and the anesthesiologists during complex cases (Hafez et al., 2021; Siller et al., 2020). Furthermore, the RDM is suitable for teaching residents and medical students (Hafez et al., 2021; Ricciardi et al., 2019a). The "Lock-on target" function is one of the most useful features of the RDM, with which the neurosurgeon hovers above the zone of interest, always in focus, maneuvering with just the foot switch. With this feature the operator

Table 1
Sixteen cranial operations were performed with the RDM in our study. The more significant data about these 16 patients is included in Table 1. The Criteria from the NASA-TLX are included in the right side of the table and the NASA Weighted Rating in the middle /more explanation in the text/.

Patient	Age	Sex	Pathology	Operation	NASA Weighted Rating	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
J.T.D.	67	female	Metastasis	Occipital craniotomy	48,00	25	25	50	55	50	50
A.P.T.	39	male	Frontal glioma	Frontal craniotomy	42,00	40	40	40	75	30	20
A.N.S.	32	female	GBM	Occipital craniotomy	56,33	75	50	75	65	50	40
Z.A.P.	64	female	Metastasis	Occipital craniotomy	55,67	55	50	60	65	50	50
Z.S.C.	46	female	Meningioma	Pterional craniotomy	52,33	70	40	60	60	45	45
J.V.G.	71	female	Metastasis	Suboccipital craniotomy	47,33	50	40	60	55	40	40
S.G.P.	62	female	GBM	Temporoparietal craniotomy	41,67	35	35	35	60	35	35
D.H.B.	58	female	Metastasis	Suboccipital craniotomy	36,67	30	35	35	55	30	30
Z.I.A.	61	female	GBM	Temporal craniotomy	33,00	20	10	10	90	15	10
P.P.S.	53	male	Hemangioblastoma	Occipital craniotomy	36,33	15	15	20	85	25	15
A.A.S.	52	male	Metastasis	Suboccipital craniotomy	30,33	10	10	10	95	5	5
M.V.T.	66	female	Meningioma	Pterional craniotomy	30,33	10	10	10	95	5	5
H.M.H.	69	male	Meningioma	Frontal craniotomy	26,67	0	0	0	100	0	0
J.D.E.	0	female	Pituitary adenoma	Pterional craniotomy	29,33	10	10	10	100	0	0
Z.I.P.	70	female	Meningioma	Parasagittal craniotomy	26,67	0	0	0	100	0	0
L.D.K.	67	female	Glioma	Frontal craniotomy	34,67	20	20	20	75	20	20

could "look around corners" in the operative field without leaving their comfortable posture, with a straight back and no neck flexion /Fig. 6/ (Hafez et al., 2021; Ricciardi et al., 2019b; Visocchi et al., 2020a). This greatly reduces the operator's effort and backpain even in long and difficult cranial cases. The constant wearing of 3D glasses is pointed out as a possible drawback [Siller et al. (2020) but in our study, such observation was not reported.

The progressive technological advancement brought a lot of supplementary devices in the operating theatre – operating microscope, high-speed drill, neuronavigation system, X-ray C- or O-arm. The correct positioning of the equipment can substantially influence the surgical workflow influencing the performance, the workload, and the operative time. In our study we have outlined a map for all those devices during spinal /Fig. 7/ and cranial /Fig. 6/ interventions. In this series we have found the RDM to be more maneuverable and less bulky than the OPMI.

However, the major asset of the RDM is probably the ability to enhance the ergonomics in the everyday neurosurgical practice (Hafez et al., 2021; Maurer et al., 2021).

Continuous neck flexion is one of the reasons for the increased neck pain in surgeons /59%/ compared to the general population /20%/ (Auerbach et al., 2011). It is reported that 73% of 417 neurosurgeons have complained of WMSDs (Gadjradj et al., 2020). Ergonomics is an emerging concept at the neurosurgical operating theatre that really needs improvement in the future. In a study by Auerbach and al. 4.6% of the surgeons were operated on for a cervical disk disease while cervical radiculopathy in the general population is quite rarer – 0.35% (Auerbach et al., 2011). The use of RDM generates no neck or back strain, typical for the use of OPMI, which suggests a significant reduction in the WMSD that are becoming widespread in the neurosurgical society /Figs. 6 and 7/. Our future study is based on the objective measurement of the impact of the RDM on ergonomics in a neurosurgical operating theatre.

Exoscopes could be the solution of the problem about ergonomics in the neurosurgical operating theatre. However, some comparative studies point out the use of exoscopes has a learning curve that is still unknown (Hafez et al., 2021). We, therefore, tried to evaluate the subjective workload of a single experienced neurosurgeon while using the RDM and based on the result draw the learning curve of the transition from OPMI to RDM. We used the NASA Task Load Index to evaluate this transition as it is a well-established, multidimentional tool for assessment of the workload while using new types of equipment. The NASA Task Load Index (NASA-TLX) is a widely used, subjective, multidimensional assessment tool that rates perceived workload in order to assess a task, system, or team's effectiveness or other aspects of performance (Hart and Staveland, 1988). It is a subjective tool; however, this could not be considered a drawback of the study as the aim is to evaluate the experience of the neurosurgeon while using a new set of equipment. An objective scale could not outline the subjective experience of any single individual. In the NASA-TLX six workload-related factors are measured and combined to derive a reliable estimate of the overall workload at the end (Hart and Staveland, 1988). The NASA-TLX has proven as a viable self-reported tool for subjective workload assessment in medical studies and even in neurosurgical studies (Schütz et al., 2021). In a few the NASA-TLX is used to evaluate the learning curve (Mohamed et al., 2014; Ruiz-Rabelo et al., 2015).

We considered that the transition was completed when a Performance above 80% was attained and the Frustration and Effort decreased below 20%. This was achieved around the 20th operation. This result was achieved earlier in spinal operations. A Performance above 80%, Frustration and Effort below 20% in spinal operations could be reached even in the 2nd operation, /Fig. 5/ while in cranial operations this result was

Table 2
Twenty-five spinal operations were performed with the RDM in our study. The more significant data about these 25 patients is included in Table 2. The Criteria from the NASA-TLX are included on the right of the table and the NASA Weighted Rating in the middle /more explanation in the text/.

Patient	Age	Sex	Pathology	Operation	NASA Weighted Rating	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
R.I.M.	66	male	Lumbar stenosis	Laminectomy, Instrumentation	49,00	55	40	45	60	50	40
L.L.N.	43	male	Lumbar disc herniation	Microdiscectomy	36,00	10	10	30	85	20	15
E.D.R.	45	male	Lumbar disc herniation	Microdiscectomy	41,00	35	35	35	80	25	20
M.K.P.	46	female	Spondylolisthesis L5-S1	Instrumentation TLIF	49,00	55	50	55	60	40	40
O.V.V.	67	male	Cervical stenosis	Laminectomy	66,33	50	55	65	80	60	65
D.G.D.	72	male	Lumbar stenosis	Interlaminotomy	41,33	40	35	35	80	25	20
S.I.S.	70	female	Lumbar spondylodiscitis	Laminectomy	48,00	50	50	50	60	40	40
N.S.	46	male	Cervical disc herniation	Interlaminotomy	35,67	30	20	20	85	15	15
P.V.P.	74	male	Synovial cyst	Interlaminotomy	35,00	25	25	25	80	15	15
N.I.N.	47	male	Lumbar stenosis	Laminectomy	34,67	10	10	20	90	20	10
R.R.K.	63	male	Cervical intramedullary tumor	Laminectomy	34,00	25	10	15	90	15	10
K.V.B.	16	male	Cervical vertebral fracture	Corporectomy, Instrumentation	30,00	10	10	10	90	10	5
S.T.R.	80	female	Thoracic vertebral fracture	Laminectomy	34,67	20	20	20	80	20	15
G.Z.G.	41	male	Lumbar disc herniation	Microdiscectomy	30,67	5	5	10	95	10	5
T.V.S.	76	female	Lumbar spondylodiscitis	Laminectomy	29,00	5	5	5	95	5	5
E.V.H.	43	female	Cervical disc herniation	Interlaminotomy	30,33	10	10	10	95	5	5
V.P.B.	67	male	Thoracic stenosis	Laminectomy	28,00	5	5	5	100	0	0
L.T.P.	74	female	Lumbar disc herniation	Microdiscectomy	29,00	5	5	5	95	5	5
D.V.Z.	33	female	Cervical disc herniation	Interlaminotomy	29,00	5	5	5	95	5	5
P.S.S.	29	female	Cervical intramedullary tumor	Laminectomy, tumor removal	29,33	10	5	5	100	5	0
I.B.T.	42	female	Cervical stenosis	Foraminotomy	26,67	0	0	0	100	0	0
I.I.I.	59	male	Synovial cyst	Hemilaminectomy	26,67	0	0	0	100	0	0
M.I.P.	43	female	Lumbar disc herniation	Microdiscectomy	26,67	0	0	0	100	0	0
P.B.A.	40	female	Intradural extramedullary Tu	Laminectomy, tumor removal	26,67	0	0	0	100	0	0
S.G.G.	67	male	Cervical stenosis	Laminectomy	26,67	0	0	0	100	0	0

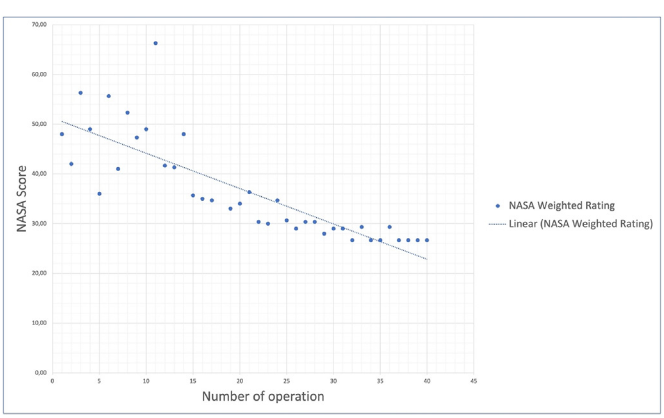

Fig. 3. The gradual decrease of the NASA weighted score for the 41 operations conducted in our study. The NASA weighted score is calculated using the NASA-TLX app with the assigned weight of every single criterion from the NASA-TLX, based on our understanding of the importance of the criteria in our daily practice /see description in the text/. High performance, low effort, low frustration is achieved after the 20th operation when the NASA weighted score is below 33–34.

reached after the 9th operation /Fig. 4/. However, according to our subjective workload measurement pilot study steady results are obtained after 20 operations with the exoscope. To our knowledge there is no single-center study about the use of RDM in the everyday neurosurgical practice and even more importantly – a study that evaluates the ease of transition from a conventional operative microscope to a Robotic Digital Microscope.

5. Conclusion

Exoscopes, including the RDM, are an emerging alternative of the conventional operative microscopes. The transition of an experienced neurosurgeon to the new tool for intraoperative visualization could be a challenge. Our study shows that this could be achieved in around 20 operations. After approximately 9 cranial operations a Performance level above 80% could be reached. This transition occurred faster with spinal procedures.

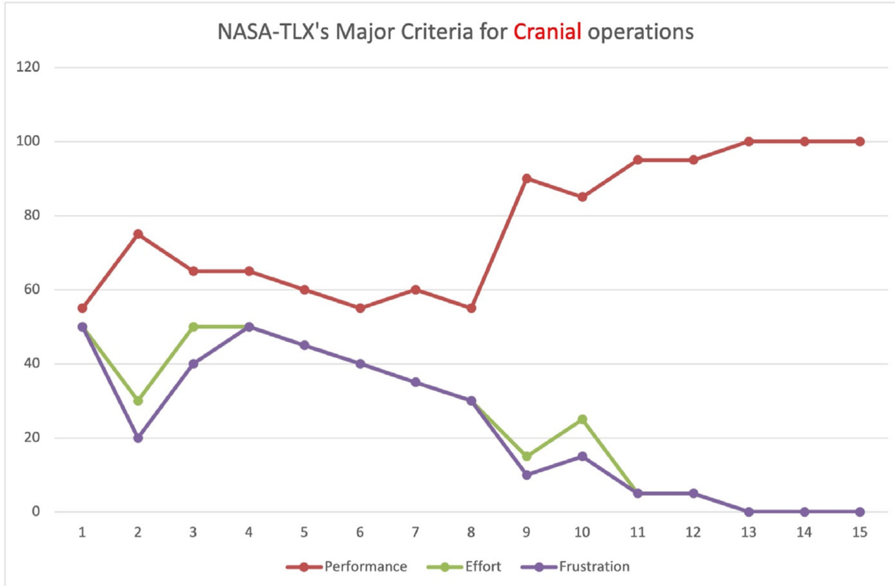

Fig. 4. The evolution of the NASA-TLX's major criteria for the cranial operations in our study - Frustration and Effort decrease below 20% after the 9th operation, the Performance is above 80% after the 9th operation.

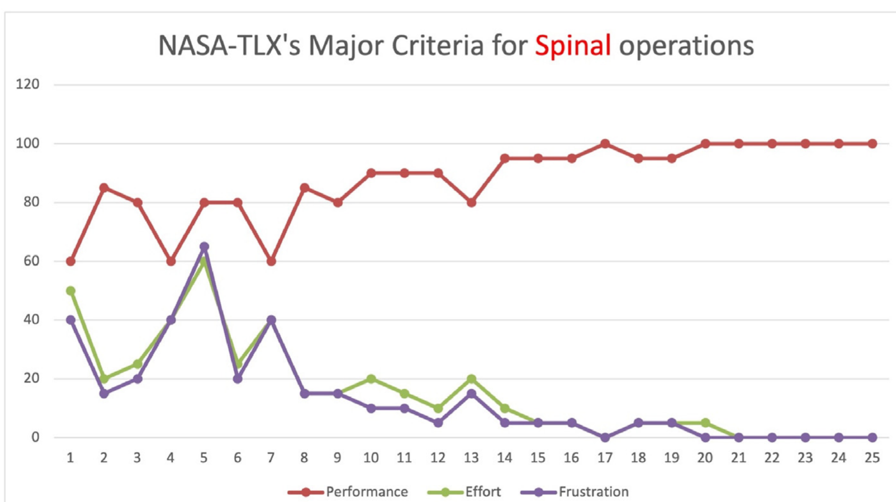

Fig. 5. The evolution of the NASA-TLX's major criteria for the spinal operations in our study – an Effort and Frustration level below 20% could be reached even after 2 operations, constant value below 20% no matter the complexity of the spinal operation is reached after the 8th operation. Same tendency is observed for the Performance – above 80% is reached after 2 operations, constant value above 80% after the 8th operation.

Fig. 6. Intraoperative photograph of the setup during a cranial operation. The Robotic Digital Microscope /marked with blue arrow/ is positioned to the right of the patient, next to the right hand of the neurosurgeon and next to the operating nurse. In this setup the main screen /yellow arrow/ of the RDM is used by the assistant and the additional wider screen /green arrow/, placed at the foot of the operating table, is used by the neurosurgeon. Notice the straight comfortable position of both neurosurgeons and the unobstructed line of view between them and the screens of the RDM. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 7. Intraoperative photograph during a spinal operation. With blue arrow is marked the RDM, which is placed behind the neurosurgeon. The long arm with mobile joints of the RDM make it possible in this position not to obstruct the line of view of the neurosurgeon to the wide screen /green arrow/. The screen of the RDM /yellow arrow/ is used by the assistant. The workstation with screens of the C-arm of the X-ray machine is marked with a grey arrow. The C-arm is removed after obtaining an intraoperative 3D image of the zone of interest and transferring the images to the neuronavigation. The camera of the neuronavigation /white arrow/ is placed at the foot of the operating table and the workstation of the neuronavigation is placed next to the wide screen of the RDM in order to be in the most convenient position for the neurosurgeon. Notice again the comfortable position of the two neurosurgeons. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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