Changing of the Guards: The Impact of Handover Procedures on Human Performance in Multiple Remote Tower Operations

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Abstract Multiple Remote Tower Operations (MRTO) change the way air traffic is managed. In this concept, air traffic control officers (ATCOs) operate several aerodromes simultaneously from a specially designed working position, also referred to as a multiple remote tower module (MRTM). This change in operations also introduces significant changes in the ATCOs' workflow and cognitive demands. In theory MRTO can facilitate the ATCOs' ability to balance their mental workload through a flexible allocation of aerodromes to each MRTM, but new procedures need to be implemented to enable such flexible allocations: Appropriate handover procedures are needed to transfer aerodromes between MRTMs and their operators. This paper investigated the feasibility of handover procedures during simulated air traffic control as a mitigation to counteract inappropriate mental workload. In a human-in-the-loop real-time simulation, six ATCOs completed traffic scenarios with or without handover via two MRTM, dealing with a total of three aerodromes. Descriptive data showed no adverse short-term effects caused by the handovers and indicated possible beneficial long-term effects on cognitive capacity and safety. The handover procedures were overall feasible and accepted by the ATCOs, as a strategy to better balance mental workload in MRTO.

Keywords Human performance · Mental workload · Situation awareness · Air traffic control · Remote tower · Multiple remote tower

1 Introduction

In recent years, with the development of new technologies, the concept of Remote Tower Operations (RTO; for an overview see Fürstenau, 2016) has gained much

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attention. RTO describes the remote surveillance of an aerodrome by means of live video feeds, as opposed to the classical out-of-the-window view from the tower. Multiple Remote Tower Operations (MRTO) take this concept a step further. Two or more remotely controlled aerodromes are managed simultaneously by one air traffic control officer (ATCO) from one Multiple Remote Tower Module (MRTM). This offers the possibility of a more flexible ATCO-aerodrome allocation, matching the actual traffic situation, e.g. by combining several smaller aerodromes in one MRTM during times of low traffic (Jakobi et al., 2019). In fact, MRTO is a concept addressing Air Traffic Services (ATS) as a whole, including air traffic advisory service, flight information service and alerting service, but this paper focusses on air traffic control service (ATC) provided by ATCOs. MRTO lead to changes in ATCOs' roles and responsibilities when controlling more than one aerodrome, and adds complexity while the basic cognitive and task demands largely remain the same (Jakobi et al., 2019).

ATCOs are expected to assure a safe, efficient and orderly flow of air traffic (Mensen, 2014)—whether they work in a conventional tower, an RTO or an MRTO workplace. In order to do that, they need to integrate information from various sources, form a mental picture of the situation and its future development, communicate effectively with other stations, such as approach and meteorology service units, and with pilots, and issue timely commands. In sum, ATC requires high levels of situation awareness (SA), and in turn high working memory capacity and attention to constantly process new information (Endsley, 1999). Such cognitive resources, however, are limited (Kahnemann, 1973; Wickens, 2002). The extent to which one's cognitive resources are used up by task demands are defined as mental workload (MWL). Excessive MWL may lead to cognitive overload, a reduction of performance, and eventually errors (Endsley, 1999; Stokes & Kite, 1997). In air traffic research, specifically, increasing MWL has been tied to a performance reduction in ATCOs (Brookings et al., 1996) and in piloting tasks (Causse et al., 2015). MWL should be kept at an acceptable level, and both too high (excessive) and too low (underutilized) MWL should be avoided in order not to impair safety (Weinger, 1999).

While prolonged periods of high MWL should be avoided, ATCOs are trained to use strategies to cope during short periods of high task load (Möhlenbrink et al., 2012). Strategies include prioritizing tasks or applying procedures to reduce the complexity of challenging situations, e.g. deferring departure flights, keeping arrival flights in holding patterns, coordinating with adjacent ATS units for delaying inbound traffic, or asking a supervisor or colleague ATCO for assistance (Möhlenbrink et al., 2012). Especially on bigger aerodromes, however, complex or highly demanding traffic situations cannot be avoided and the ATCOs' personal coping skills and strategies may be insufficient to counteract high MWL. This requires basic organizational countermeasures like shorter shifts, more frequent breaks, splitting the ATC task into several roles (clearance delivery, ground, or runway/local controller), permanent double staffing (executive and planning ATCO), and supervisor positions. In addition, technical support can further reduce task demands, e.g. with approach radar, surface movement radar, electronic flight strips with planning assistance functionality, or conflict monitoring tools.

All these considerations also apply to MRTO, where controlling several aerodromes adds to the complexity of the ATC task. However, some coping mechanisms that are effective for controlling only one aerodrome may prove ineffective for MRTO. A complex situation or incident occurring at one aerodrome may indirectly influence all other aerodromes controlled by the same ATCO, because of the necessity to focus their limited cognitive resources on a single problem. Coordination with adjacent ATS units or aerodrome services is multiplied by the number of aerodromes in the MRTM, and delays due to holding traffic may affect all aerodromes instead of only one. There is a need for appropriate procedures to ensure that ATCOs working in MRTO can balance their MWL and assure a safe, efficient and orderly flow of air traffic just as well as ATCOs working in RTO or conventional towers. One possible strategy is handover procedures. Handover procedures, in this paper "handovers", allow the swift transfer of one or more aerodromes from one ATCO and MRTM to another. This will enable ATCOs to reduce their task load in order to counteract high MWL or concentrate on one incident, as well as ensure that the capacity of, or service level provided to the other aerodromes will not be reduced.

The aim of this paper is to assess the general feasibility of handovers in MRTO by investigating their impact on ATCOs' mental capacity. In this study, we focused on the ATCOs handing over aerodromes to a colleague ATCO. We hypothesized that the procedures would not induce negative short-term effects on safety and ATCOs' MWL and SA during handover. Furthermore, we expected beneficial long-term effects for the ATCOs who handed over aerodromes, indicated by lower MWL and higher SA after handover compared to without.

In the present paper, we present questionnaire data. Concurrent eye tracking data are analysed and presented separately in Friedrich et al. (2020).

2 Method

2.1 Participants

Six active Air Traffic Control Officers (ATCOs) from a Northern European air navigation service provider took part in the experiment. All were male, aged between 25 and 37 years ($M = 29.6$, $SD = 3.9$) and with job experience ranging between 1.5 and 8 years ($M = 3.9$, $SD = 2.4$). The ATCOs participated voluntarily during their working hours. The study was performed in accordance with the General Data Protection Regulation (EU) 2016/679.

2.2 *Design and Material*

The study was conducted in the Tower Lab research facility at DLR Braunschweig. Two MRTMs as shown in Fig. 1 were provided. Up to three aerodromes can be operated from one MRTM. Each MRTM consisted of the following parts: panoramic view (208° horizontal and 32° vertical) and panel for a pan-tilt-zoom camera for each aerodrome, stacked on top of each other; radar, and electronic flight strip system (Frequentis AG, Vienna, Austria) for each aerodrome in corresponding order from left to right; radio communication with coupled frequency for all three aerodromes; separate telephone connection for each aerodrome for local aerodrome services. The experiment was performed as a human-in-the-loop real time simulation on an NLR Air Traffic Control Research Simulator (NARSIM; Have, 1993).

Two independent variables (IV-A and IV-B) were varied in two levels each (see Table 1). IV-A "Non-Nominal Situation" varied in A1 "Increased Traffic Load", and A2 "Emergency". IV-B "Handover" varied in B1 "Without", and B2 "With". Every

Fig. 1 Multiple remote tower module (MRTM) as used in the study (two active ATCOs with an observer right beside them)

Table 1 Experimental design with independent variables (IV-A, IV-B) forming Four experimental conditions (EC)

		IV-A Non-nominal situation	
		A1 *Increased traffic load*	A2 *Emergency*
IV-B Handover	B1 *Without*	EC_{11}	EC_{21}
	B2 *With*	EC_{12}	EC_{22}

participant completed every experimental condition. This resulted in a complete 2×2 factor within-subject design. To reduce learning effects, aircraft call signs were varied and arrival and departure times shifted slightly between conditions.

The ATCOs controlled up to three aerodromes in parallel, two small and a medium-sized one. In each experimental condition the ATCOs had to control a traffic scenario with an average traffic load of 28 movements per hour (ground vehicles included). The traffic was composed of 90% IFR (instrument flight rules) and 10% VFR (visual flight rules) traffic. The overall traffic load was unevenly distributed between the aerodromes with the larger aerodrome accounting for approx. 50% of the traffic and the smaller aerodromes for 25% each. The simulated weather always met visual meteorological conditions (VMC) with no clouds. The time of day was always day time.

In order to enable handover procedures, the six participants worked together in groups of two, forming three dyads. Each participant completed all experimental conditions as Lead ATCO (the one handing over traffic) and as Support ATCO (the one receiving traffic). For conditions without handover ("*Without*"; EC_{11}, EC_{21}) only the participant performing the role of the Lead ATCO was present and no traffic was handed over. The conditions were presented in a pseudo-randomized order (see Sect. 2.2.3), for a detailed description). The MRTM station on the right side of the room was always the main MRTM occupied by the Lead ATCO. The left MRTM was only opened and manned with the Support ATCO in experimental conditions involving a handover ("*With*"; EC_{12}, EC_{22}).

2.2.1 Implementation of the UV-B "Handover"

The handover procedures were designed in a human-centred approach with feedback from ATCOs prior to the study, and provided a scaffold for all relevant information to be shared. The participants were asked to perform handovers in a standardized way: The Lead ATCO was permitted to request a colleague to take over aerodromes. If no request was made by a pre-defined time, the decision to open the second position was made by a confederate supervisor in order to ensure the experimental procedure was carried out as planned. The aerodromes to be handed over were fixed pre-experiment. The Support ATCO was then fetched from the break room by the confederate supervisor. The Support ATCO sat down at their work station and would turn on the panoramic view and radio communication for the aerodromes the Lead ATCO was working on. This way the Support ATCO was able to gather information on the situation in order to build up a mental traffic picture prior to the actual handover. The Lead ATCO initiated the handover and ensured that the Support ATCO was ready to take over. Both went through the standardized handover checklist to ensure all information was shared, with the Lead ATCO giving information and the Support ATCO confirming the correct understanding. At the end of the handover, the Lead ATCO gave control to the Support ATCO, who confirmed the takeover. The Lead ATCO then turned off their panoramic view and radio communication for the aerodrome handed over to Support. If two aerodromes were to be handed over, this was done in consecutive order and both ATCOs would run through the checklist twice. Handovers could always be interrupted by incoming radio communication. One full handover procedure took approximately 20–30 s, depending on traffic and runway conditions.

2.2.2 Levels of the UV-A "Non-nominal Situation"

Level "Increased Traffic Load"

One experimental run lasted approx. 55 min. It included a traffic peak around minute 15 (increasing and coinciding traffic on all three aerodromes) and a bird strike (i.e. collision between a bird and a departing aircraft) on one aerodrome around minute 40. In the "*With*" handover experimental condition, the Lead ATCO was informed about the traffic peak by a confederate Supervisor (DLR member) five minutes in advance and asked to hand over one predefined aerodrome to the Support ATCO. This aerodrome was the one with the bird strike. Around minute 45 the Lead ATCO was told to prepare to receive back the aerodrome, when the bird strike incident was solved. The Lead ATCO continued working on three aerodromes until the end of the run. In the "*Without*" handover condition, no handover took place and the ATCO had to manage both the traffic peak and bird strike.

Level "Emergency"

One experimental run lasted approx. 40 min. Around minute 10, the Lead ATCO received a call informing them about an incoming aircraft with an emergency. The aircraft was scheduled for minute 25 so the Lead ATCO had time to prepare. In the "*With*" handover condition they should request the Support ATCO and hand over the two aerodromes that were not affected by the emergency. The aerodromes were not handed back later and the Lead ATCO kept working with only one aerodrome until the end of the run. In the "*Without*" handover condition, no handover took place. The nature of the emergency was varied between "*With*" and "*Without*" handover to counteract learning effects. For "*With*", an engine failure and for "*Without*" a medical emergency was announced, both situations in which the pilots were forced to send a "Pan-Pan" urgency signal call. The affected aircraft, timing and response vehicles (fire trucks for the engine failure, ambulance for the medical emergency) were varied and the nature of the respective emergency required the ATCOs to ask the pilots for different information. Both situations, however, resulted in temporary closure of the runway and the need for coordination with aerodrome and approach service officers.

2.2.3 Experimental Protocol

The ATCOs participated in fixed dyads, i.e. the same two ATCOs worked together for the duration of the experiment. They completed all experimental conditions on two consecutive days, three runs on day 1 and five runs on day 2. On day 1 the ATCOs received information about the aim of the study and gave informed written consent. They were then instructed how to operate the MRTM and received 80 min of training including handovers (40 min each as Lead and Support). They then proceeded to the experimental conditions. In total, every participant completed six runs: Two "*Without*" handover (i.e. as the only ATCO), and four "*With*" handover (i.e. two as Lead ATCO and two as Support ATCO). In a "*Without*" handover condition only one participant would complete the run while the other one could take a break. The order of the conditions was pseudo-randomized, such that one participant would never be Lead ATCO (or only ATCO in "*Without*" handover conditions) in consecutive runs. This resulted in an alternating sequence of being Lead/only ATCO and Support ATCO/having a break.

On day 2 the experiment continued and was concluded with a debriefing session. At the beginning of each run the ATCOs controlled all three aerodromes. The ATCOs were told they would encounter special situations during the experiment and could request their colleague as Support. A DLR member served as a Supervisor and informed the ATCO when a handover was necessary or, in case of a "*Without*" handover condition, not possible.

2.2.4 Human Performance Assessment

Mental Workload

Mental workload (MWL) was assessed with the short version of the Assessing the Impact on Mental Workload questionnaire (AIM-s; Dehn, 2008), Bedford scale (Roscoe, 1984; Roscoe & Ellis, 1990) and the Instantaneous Self-Assessment of Workload technique (ISA; Tattersall, 1994; Tattersall & Foord, 1996). The AIM-s assesses the impact of automation on MWL. It is rated on a 0–6 scale ("strongly disagree" to "strongly agree") with 6 indicating the highest MWL. The questionnaire consists of 16 items, of which only 14 were used in the experiment. Two items were excluded because they focused on team interactions that were not part of the experiment. The remaining 14 items were then averaged to provide a final score.

The Bedford scale promotes self-assessment of the experienced MWL on a 1–10 scale (1 = insignificant; 10 = unable to perform task).

The ISA scale is used to assess current MWL during the task. It is answered on a 0–5 scale (0 = underutilized; 5 = excessive). Every five minutes the participants were asked to rate their MWL of the previous five-minute period.

Situation Awareness

Situation awareness (SA) was assessed with the China Lake Situation Awareness scale (CLSA; Adams et al., 1998) and the Situation Awareness for SHAPE questionnaire (SASHA; Dehn, 2008). The CLSA assesses SA on a 1–10 scale (1 = far too low; 10 = excellent). The SASHA questionnaire addresses SA in six items on a 0–6 scale ("strongly disagree" to "strongly agree") with 6 indicating the best SA. The six items are then averaged to provide a final score.

Safety

The Cooper-Harper scale (Cooper & Harper, 1969) adapted to fit the ATC context was used for retrospective self-assess of safety impairment. ATCOs were asked to rate the most challenging or critical situation from the previous run. The adapted Cooper-Harper scale is rated from 1–10. Values 1–3 indicate no to minor impairment (low to slightly increased MWL). Values 4–6 indicate an impairment of efficiency (having caused "minor unpleasant" to "very disturbing" traffic delays). Values 7–10 indicate an impairment of safety ("loss of ability to plan ahead" to "not being able to control the traffic any more").

Impact of Handover Procedures

Additional tailored questions were asked to assess the ATCOs' experience of the handover procedures.

After "*Without*" handover conditions, ATCOs were asked if a handover would have helped them to balance their WL and SA. After "*With*" Handover conditions, ATCOs were asked which impact the handover procedure had on their WL and SA, and whether they considered a handover an appropriate measure during traffic peaks or emergency situations. Answers were given on a 0–6 scale ("strongly disagree" to "strongly agree").

"*Without*" handover conditions:

1. I felt confident I could handle the traffic on my own.
2. Handing over traffic to a colleague would have helped me maintain my situation awareness.
3. Handing over traffic to a colleague would have helped me balance my workload.

"*With*" handover conditions—Increased Traffic Load/[Emergency]:

1. I was able to hand over an aerodrome [two aerodromes] to my ATCO colleague in a safe and efficient way.
2. During the handover procedure I lost track of the traffic.
3. Handing over the aerodrome to my colleague was demanding.

4. Handover is an appropriate measure to counteract high task load [emergency] situations.

2.2.5 Analysis

For this paper, only data from the "*Without*" handover conditions and the Lead ATCOs' data from the "*With*" handover conditions were evaluated as the aim was to assess the impact of the handover procedure on ATCOs handing over aerodromes to a colleague. Comparisons are made between the two levels of IV-B ("*Without*" vs. "*With*" handover) in each IV-A level ("*Increased Traffic Load*" and "*Emergency*"). The data from the tailored questionnaires on handover procedures are evaluated separately for "*With*" and "*Without*" handover conditions as the questions differed between the conditions. Because of the low sample size, only descriptive data are reported.

3 Results

Due to the small sample size the data are not normally distributed and show high variance, as can be seen in high standard deviations for most of the results. Between-subject outliers were plotted and visual inspection showed that the high variance was not due to the answer tendencies of particular participants. Therefore, no outliers were excluded. Because of these limitations, the results should be interpreted cautiously.

3.1 Mental Workload

The success of the experimental manipulation of MWL was checked using the ISA data. The introduction of special situations (traffic peak and bird strike for "*Increased Traffic Load*"; aircraft emergency in "*Emergency*") is associated with rising MWL levels in the "*Without*" handover conditions (see Table 2 and Fig. 2). This can be interpreted as a successful induction of an increase in MWL.

For possible beneficial effects of handovers on MWL, the conditions "*With*" and "*Without*" are compared. In the "*Increased Traffic Load*" conditions (Fig. 2, upper panel), mean values for "*With*" handover were constantly lower than for "*Without*". Additionally, in the "*With*" condition the MWL peak in minute 45 (bird strike) is not visible: The incident did not affect the Lead ATCO as it happened on the aerodrome given over to the Support ATCO. In the "*Emergency*" conditions (Fig. 2, lower panel), mean ISA scores did not differ between "*With*" and "*Without*" handover until the onset of the special situation (i.e. information about the emergency aircraft). After situation onset and handover, the mean scores were higher in the "*Without*" handover condition compared to "*With*".

Table 2 ISA data on mental workload (lead ATCOs only)

Measure (values)	IV-A	IV-B	Mean ISA values after x minutes (SD)										
			05	10	15	20	25	30	35	40	45	50	55
ISA (1–5)	Increased traffic load	Without	1.60 (0.55)	3.20 (0.84)	3.00 (0.71)	3.80 (0.84)	3.40 (1.14)	2.80 (0.84)	2.50 (1.05)	3.40 (1.14)	3.83 (0.75)	3.17 (1.17)	2.60 (1.14)
		With	1.00 (0.00)	2.67 (0.52)	2.33 (0.52)	3.00 (0.63)	2.67 (0.82)	1.83 (0.41)	2.00 (0.63)	2.60 (0.89)	2.50 (1.05)	2.67 (0.52)	2.00 (0.71)
	Emergency	Without	1.00 (0.00)	2.75 (0.50)	3.20 (0.84)	3.40 (0.55)	3.00 (0.82)	2.80 (0.84)	3.25 (0.50)	–	–	–	–
		With	1.17 (0.41)	3.00 (0.63)	3.33 (0.82)	3.00 (0.89)	2.40 (0.55)	2.33 (0.82)	2.17 (0.41)	–	–	–	–

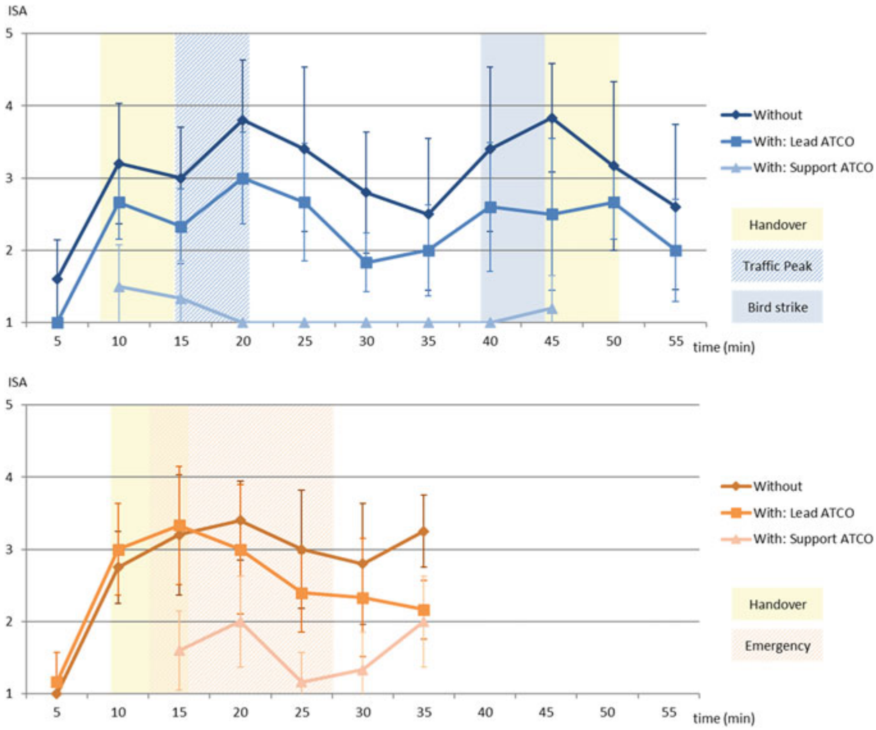

Fig. 2 Mean ISA values with standard deviations over time for "Increased Traffic Load" (upper panel) and "Emergency" (lower panel) conditions. Highlighted areas indicate time windows in which special situations took place. Onset and duration of the special situations could vary depending on ATCOs' actions and the simulated traffic

Exploratory evaluation of corresponding Support ATCOs' ISA data indicates overall low MWL levels (Fig. 2). In the "*Increased Traffic Load*" condition, slightly higher values can be observed during the initial handover, followed by a period of very low MWL. The special situation (i.e. bird strike) did not inflict a meaningful increase in MWL. In the "*Emergency*" condition, ISA scores varied more and were higher than in the "*Increased Traffic Load*" condition, indicating a possible main effect of IV-A (non-nominal situation) due to the amount of traffic the Support ATCOs received.

MWL ratings collected post-run indicate medium to slightly elevated MWL levels for all experimental conditions (Table 3). In the "*Increased Traffic Load*" condition, data of the Bedford scale show a lower mean and lower standard deviations in the "*With*" handover condition compared to "*Without*". This could indicate a possible beneficial effect of handover in terms of lower and more equal MWL ratings. This effect cannot be found in the "*Emergency*" conditions (Fig. 3). AIM-s data show no noticeable differences between conditions (Fig. 4).

Table 3 Questionnaire data on mental workload

Measure (values)	IV-A	IV-B	Min	Max	M	SD
Bedford scale (1–10)	Increased traffic load	Without	3.00	9.00	6.00	2.76
		With	3.00	5.00	3.67	0.82
	Emergency	Without	4.00	8.00	5.17	1.47
		With	3.00	8.00	5.33	1.63
AIM-s (0–6)	Increased traffic load	Without	2.29	5.21	3.70	1.15
		With	1.14	5.00	3.38	1.33
	Emergency	Without	2.36	4.93	3.49	0.95
		With	3.21	4.36	3.73	0.47

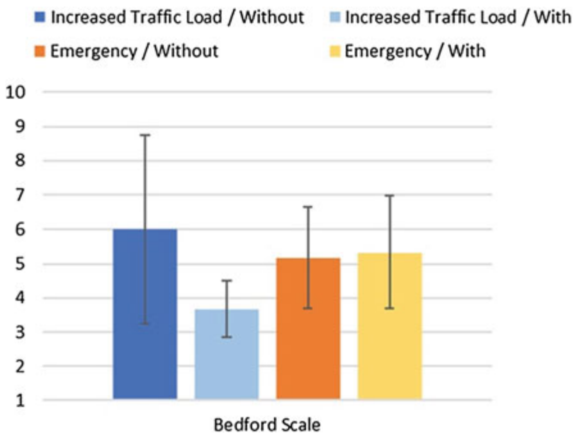

Fig. 3 Mean values of the Bedford Scale MWL assessment (error bars indicate SD)

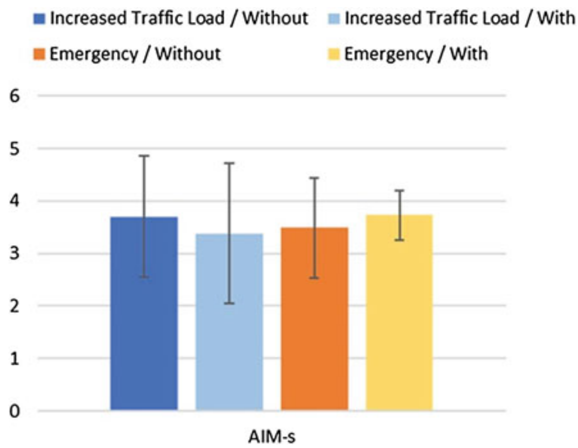

Fig. 4 Mean values of the AIM-s MWL assessment (error bars indicate SD)

In sum, these findings show successful MWL manipulation and hint to a main effect of IV-B (handover) on MWL.

3.2 *Situation Awareness*

Retrospective SA ratings indicate medium to high SA levels for all experimental conditions (Table 4). In the "*Increased Traffic Load*" conditions, CLSA data indicate slightly higher mean values and lower standard deviations for "*With*" than "*Without*" (Fig. 5). This could indicate a possible beneficial effect of handover in terms of higher and more equal SA ratings. This effect cannot be found in the "*Emergency*" conditions.

Data of the SASHA show very similar means and standard deviations for both "*Increased Traffic Load*" conditions (Fig. 6). In comparison, the

Table 4 Questionnaire data on situation awareness

Measure (values)	IV-A	IV-B	Min	Max	M	SD
CLSA (1–10)	Increased traffic load	Without	5.00	8.00	6.83	1.47
		With	7.00	9.00	7.67	0.82
	Emergency	Without	5.00	8.00	6.67	1.03
		With	5.00	8.00	6.83	0.98
SASHA (0–6)	Increased traffic load	Without	3.00	4.83	3.92	0.81
		With	2.17	5.00	3.94	0.95
	Emergency	Without	2.83	4.83	3.92	0.74
		With	2.83	4.50	3.56	0.66

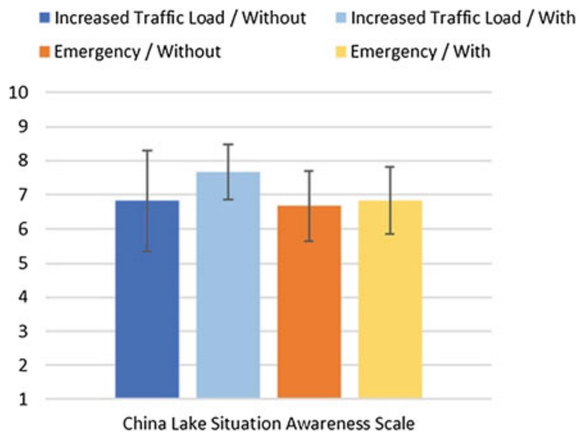

Fig. 5 Mean values of the China Lake SA assessment (error bars indicate SD)

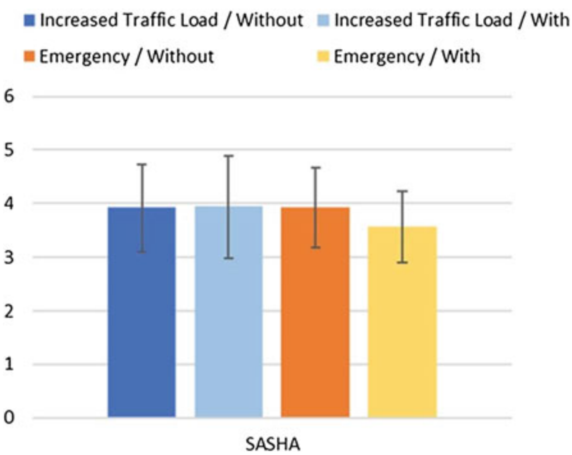

Fig. 6 Mean values of the SASHA SA assessment (error bars indicate SD)

"*Emergency/With*" condition displays a slightly lower mean and standard deviation than "*Emergency/Without*". In sum, no clear effect of handover on SA could be found.

3.3 Safety

Retrospective self-assessment of critical situations shows no impairment of safety. Maximum values indicate impairment of efficiency (values 4–6), with "minor unpleasant delays" for the "*Emergency/Without*" condition and "very disturbing delays" for all other conditions. Regarding mean values, the "*Emergency/With*" condition shows the highest efficiency impairment rating. This could indicate a possible negative effect of handover in emergency situations in terms of efficiency. In sum, no safety impairments and no clear effect of handover on safety could be found (Table 5 and Fig. 7).

Table 5 Adapted Cooper-Harper scale data on safety

Measure (values)	IV-A	IV-B	Min	Max	M	SD
Adapted Cooper-Harper scale (1–10)	Increased traffic load	Without	3.00	6.00	4.17	1.17
		With	2.00	6.00	3.83	1.33
	Emergency	Without	3.00	4.00	3.67	0.52
		With	3.00	6.00	4.67	1.21

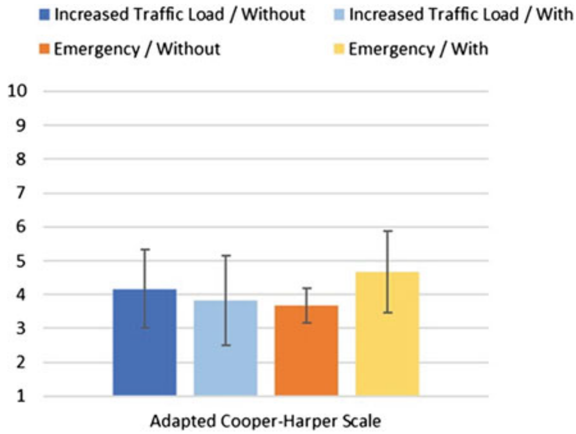

Fig. 7 Mean values of the adapted Cooper-Harper scale for all four experimental conditions (error bars indicate SD)

3.4 Impact of Handover Procedures

In "*Without*" handover conditions, mean values indicate a medium to high confidence in the participants' own ability to handle the traffic on their own (see Table 6 and Fig. 8). A high standard deviation and large data range indicate large individual differences, with some participants stating very low confidence. Concerning the questions regarding a possible benefit of handover on SA and MWL, data show medium to high agreement. This indicates the participants would have welcomed the possibility of a handover. The findings did not differ between IV-A (non-nominal situations) conditions.

In "*With*" handover conditions (see Table 7 and Fig. 9), the ratings indicate large individual differences between participants for SA and MWL, regardless of the IV-A level. The ability to hand over aerodromes, too, shows large differences in "*Increased Traffic Load*" but not in "*Emergency*" that poses an exception with strong agreement between participants. Participants unanimously viewed handover procedures

Table 6 Questionnaire data on handover procedures—"Without" handover

Measure (values)	IV-A	Min	Max	M	SD
Confidence handling traffic alone (0–6)	Increased traffic load	0.00	5.00	3.50	2.35
	Emergency	1.00	5.00	3.83	1.84
Benefit of handover on SA (0–6)	Increased traffic load	3.00	6.00	4.50	1.38
	Emergency	3.00	6.00	4.83	0.98
Benefit of handover on MWL (0–6)	Increased traffic load	3.00	6.00	5.00	1.10
	Emergency	3.00	6.00	4.67	1.03

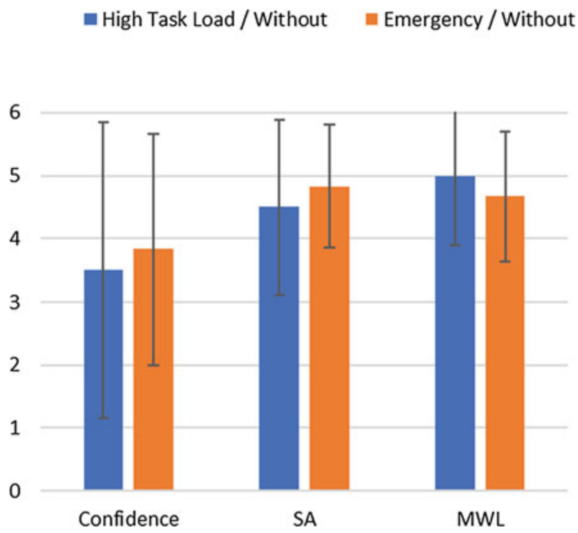

Fig. 8 Mean values of the tailored questions on handover procedures—"Without" conditions (error bars indicate SD)

Table 7 Questionnaire data on handover procedures—"With" handover

Measure (values)	IV-A	Min	Max	M	SD
Ability to hand over aerodrome(s) (0–6)	Increased traffic load	1.00	6.00	4.17	1.72
	Emergency	4.00	5.00	4.50	0.55
Loss of SA during handover (0–6)	Increased traffic load	0.00	4.00	1.83	1.47
	Emergency	1.00	4.00	2.00	1.27
Increase in MWL during handover(0–6)	Increased traffic load	1.00	5.00	3.17	1.72
	Emergency	2.00	5.00	3.17	1.17
Handover as appropriate mitigation (0–6)	Increased traffic load	4.00	6.00	4.83	0.75
	Emergency	4.00	6.00	5.17	0.75

as an adequate countermeasure for situations involving increased traffic load and emergencies, as seen by high mean values and comparably low standard deviations.

In sum, tailored questions show that the impact of handovers on participants differed substantially, yet all participants considered handovers an appropriate mitigation for demanding situations.

4 Discussion

The aim of this paper was to assess the general feasibility of handover procedures in an MRTO setting by investigating their impact on safety, and ATCOs' MWL and SA. This paper focused on the ATCOs dealing with three aerodromes of which one or two

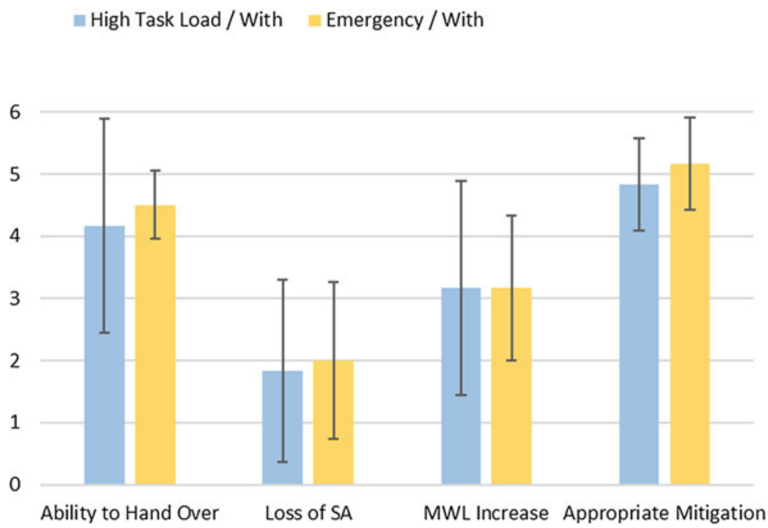

Fig. 9 Mean values of the tailored questions on handover procedures—"With" conditions (error bars indicate SD)

could be handed over to a colleague ATCO. We hypothesized that handover procedures would not cause immediate negative effects on MWL, SA and safety during handover (no negative short-term effects), and would in turn lead to a lasting reduction in MWL and increase in SA after handover procedures were applied (beneficial long-term effects).

Given the small sample size, no inferential statistical analyses were performed and descriptive data was presented instead. Overall, high standard deviations were observed, indicating large individual differences. The results therefore likely reflect participants' individual skills, attitudes, and a complicated interaction between experimental conditions, own actions and interaction with the team partner. We therefore very cautiously draw conclusions and give recommendations for further studies.

Results of the ISA data indicate that our manipulation of MWL by means of special situations worked. Yet, we did not induce excessive MWL in conditions without handover. Especially the emergency situation seems not to have elicited excessive cognitive demands. The hypothesized beneficial effect of handovers should manifest itself most prominently in situations where the ATCOs' mental capacity is exceeded and they need to use a coping strategy. It is therefore possible that our MWL manipulation was not strong enough to show the hypothesized handover effects. Future studies should use a higher traffic volume and/or more challenging situations in order to induce higher cognitive demands.

The handover procedures performed in this study did not seem to have interfered with participants' ability to perform their tasks. On average, their SA and MWL remained on a medium level during handover, but showed high individual differences. This could be explained with traffic at hand during handover that may have disrupted the procedure and caused additional cognitive load in some situations. Yet, the participants were able to hand over the aerodromes in a safe and efficient way and viewed handovers as an appropriate mitigation to counteract demanding situations. Furthermore, they would have welcomed the possibility of a handover in runs where this was not possible. These findings highlight that while the handover process itself may add additional load in certain situations, ATCOs consider handovers a useful strategy to balance their MWL in demanding situations.

Concerning beneficial long-term effects of handovers, our data show mixed results. There is first evidence that handovers may be able to reduce MWL by reducing task load in the long term. These effects seem stronger for increased traffic load than emergency situations. Our data did not show a clear direction of the effect of handovers on SA. Similar to the MWL effects, handovers may be able to increase and equalize SA across participants for increased traffic load situations. By contrast, SA was reduced in emergency situations with handover. This pattern could also be observed in the safety ratings. Even though safety was never impaired in any condition, efficiency was impacted most in the "*Emergency/With*" handover condition.

This could point towards an adverse effect of handover in emergency situations or an unfavourable interaction of both variables. An alternative explanation lies in the nature of the emergency situations used in this study. As pointed out in section "Level "Emergency"", we used two different emergencies to counteract learning effects. The emergency used in runs without handover was a medical emergency aboard an aircraft, while the emergency in runs with handover was an aircraft with an engine failure. Even though the actions to be undertaken by the ATCOs were largely the same (runway closure, coordination with the pilot and other units, etc.), the engine failure emergency may have been perceived as more difficult. With the possibility of a fire and casualties upon landing, the consequences of this emergency, even though simulated, may have seemed more severe. This could have induced more stress and forced the ATCO to direct more cognitive resources towards the situation than in the medical emergency situation. This way the nature of the emergency would have impacted the retrospective SA and safety assessments more than the handover, and positive handover effects could have been masked. This explanation is also supported by the MWL findings: While the on-task assessment (ISA) showed lower MWL levels following handovers in all conditions, the retrospective assessments only show this effect for the increased traffic load situation and no difference between the emergency conditions. The comparability of our emergency conditions may therefore be limited. We advise that for further investigations of the effect of handovers in emergency situations, the nature of the situation should be kept constant, and learning effects should be counteracted by other measures like greater variation in aircraft arrival and departure times.

Taken together, this study provides hints towards the usefulness of handovers as a mitigation for demanding situations in MRTO. Even though handovers might induce additional MWL during the procedure, our data suggests beneficial long-term effects. The high approval from the participants is an additional benefit. Apart from objective positive effects, handovers have the potential to positively influence

ATCOs' confidence. The knowledge that they can get support and give away traffic if they feel the need to do so could reduce stress levels and improve the acceptance of the transition from conventional towers or RTO to MRTO.

Nevertheless, more empirical evidence is needed in order to assess effects of handover procedures on ATCOs' MWL and SA, especially during the handover itself. In addition to subjective and retrospect ratings, physiological measurement of MWL could shed light on the impact on cognitive resources during and after handover. Electroencephalography (EEG), for example, has proved useful for the classification of MWL (Causse et al., 2015; Radüntz, 2017; Radüntz et al., 2020), providing both high temporal resolution and an objective assessment. In addition to MWL and SA, future research should also investigate the effects of handovers on the development of mental fatigue (e.g. Fatigue Instantaneous Self-Assessment F-ISA; Hamann & Carstengerdes, 2020) and sleepiness (e.g. Karolinska Sleepiness Scale KSS; Akerstedt & Gillberg, 1990) during ATS shifts. We therefore encourage research on this topic with additional (physiological) measurements, larger samples, as well as more challenging traffic scenarios including a wider variety of unexpected situations and weather conditions. The interaction between ATCOs and our dyadic team approach pose another methodological challenge: A nested design. Interactions and learning curves might differ between ATCO dyads and could influence the efficacy of communication during handovers. A multi-level analysis approach could shed light on team dynamics and improve handover procedures further.

In the future, handovers could not only prove to be a useful strategy to reduce cognitive demands. This study focused on inflicting high levels of MWL with a high traffic volume and special situations in order to see if handing over traffic to a colleague could mitigate these effects. Having shown that aerodromes can be handed over safely and efficiently, we hypothesize that this strategy could be used to balance ATCOs' MWL in both directions: from excessive down and from underutilized up to an acceptable level. The ISA data we collected from the Support ATCOs showed a pattern that could be interpreted as a floor effect. The ATCOs were underutilized most of the time, especially with only one aerodrome in the "*Increased Traffic Load*" condition. In conventional towers the ATCOs can only work with the traffic at hand. In case of a small, low frequented aerodrome the task load may prove insufficient and ATCOs could be underutilized for long periods. This poses a safety risk since ATCOs are prone to lose vigilance and risk a slow but steady decline of their ATS skills when they do not train them in day-to-day operations (Weinger, 1999). MRTO offer the possibility to enlarge and enrich chronically underutilized ATCOs' work. The flexible addition of aerodromes and thereby traffic as well as responsibility could foster job satisfaction and counteract the detrimental effects of long periods of being underutilized. In ATC, task load and complexity do not remain the same; instead they oscillate during the day. MRTO provide an opportunity to flexibly allocate aerodromes to ATCOs and hand over aerodromes when needed. During peak times or highly complex situations, ATCOs could hand over an aerodrome when they feel the need to, while underutilized ATCOs could accept another aerodrome to increase their MWL to a comfortable level. Therefore, future research should focus on both, MWL reduction and increase depending on the situational needs and ATCOs' level of comfort. If handovers can be used to regulate ATCOs' MWL in both directions, they will become a powerful strategy for ATCOs. Making handovers an inherent part of the concept would give MRTO the potential to let ATCOs regulate their MWL depending on the situation, whilst ensuring a safe, efficient and orderly flow of air traffic at the same time.

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References

Adams, S. R., Kane, R., & Bates, R. (1998). *Validation of the China Lake Situational Awareness scale with 3D SART and S-CAT (452330D).* China Lake, CA. Naval Air Warfare Center Weapons Division.

Akerstedt, T., & Gillberg, M. (1990). Subjective and objective sleepiness in the active individual. *The International Journal of Neuroscience, 52*(1–2), 29–37. https://doi.org/10.3109/00207459008994241

Brookings, J. B., Wilson, G. F., & Swain, C. R. (1996). Psychophysiological responses to changes in workload during simulated air traffic control. *Biological Psychology, 42*(3), 361–377. https://doi.org/10.1016/0301-0511(95)05167-8

Causse, M., Fabre, E., Giraudet, L., Gonzalez, M., & Peysakhovich, V. (2015). EEG/ERP as a measure of mental workload in a simple piloting task. *Procedia Manufacturing, 3*, 5230–5236. https://doi.org/10.1016/j.promfg.2015.07.594

Cooper, G. E., & Harper, R. P., JR. (1969). *The use of pilot rating in the evaluation of aircraft handling qualities (TN-D-5153).* Moffet Field, California, USA. National Aeronautics and Space Administration, Ames Research Center. https://ntrs.nasa.gov/citations/19690013177

Dehn, D. M. (2008). Assessing the impact of automation on the air traffic controller: The SHAPE questionnaires. *Air Traffic Control Quarterly, 16*(2), 127–146. https://doi.org/10.2514/atcq.16.2.127

Endsley, M. R. (1999). Situation awareness in aviation systems. In D. J. Garland (Ed.), *Human factors in transportation. Handbook of aviation human factors.* Erlbaum.

Friedrich, M., Hamann, A., & Jakobi, J. (2020). An eye catcher in the ATC domain: Influence of multiple remote tower operations on distribution of eye movements. In D. Harris & W.-C. Li (Eds.), *Lecture Notes in Computer Science. Engineering Psychology and Cognitive Ergonomics. Cognition and Design* (17th Ed., Vol. 12187, pp. 262–277). Springer Nature. https://doi.org/10.1007/978-3-030-49183-3_21

Fürstenau, N. (Ed.). (2016). *Research topics in aerospace. Virtual and remote control tower: Research, design, development and validation.* Springer International Publishing. http://gbv.eblib.com/patron/FullRecord.aspx?p=4528419. https://doi.org/10.1007/978-3-319-28719-5

Hamann, A., & Carstengerdes, N. (2020). *Fatigue Instantaneous Self-Assessment (F-ISA): Development of a short mental fatigue rating* (DLR-IB-FL-BS-2020–64). Braunschweig. Deutsches Zentrum für Luft- und Raumfahrt, Institut für Flugführung.

ten Have, J. M. (1993). The development of the NLR ATC Research Simulator (Narsim). *Simulation Practice and Theory, 1*(1), 31–39. https://doi.org/10.1016/0928-4869(93)90009-F

Jakobi, J., Hamann, A., Filipp, M., Kaufhold, R., & Priboj, O. (2019). Final project report: Project "PJ05 Remote Tower". Grant no.: 730195, Call H2020-SESAR-2015–2, Topic SESAR.IR-VLD.Wave1–08–2015. https://www.sesarju.eu/sites/default/files/documents/projects/FPR/PJ05_D2.1_Final%20Project%20Report.pdf

Kahnemann, D. (1973). *Attention and effort*. Prentice-Hall.
Mensen, H. (2014). Moderne Flugsicherung: Organisation, Verfahren, Technik (4. Aufl.). VDI-Buch. Springer Vieweg. https://doi.org/10.1007/978-3-642-54294-7
Möhlenbrink, C., Papenfuss, A., & Jakobi, J. (2012). The role of workload for work organisation in a remote tower control center. *Air Traffic Control Quarterly, 20*(1), 5–26.
Radüntz, T. (2017). Dual frequency head maps: A new method for indexing mental workload continuously during execution of cognitive tasks. *Frontiers in Physiology, 8*, 1019. https://doi.org/10.3389/fphys.2017.01019
Radüntz, T., Fürstenau, N., Mühlhausen, T., & Meffert, B. (2020). Indexing mental workload during simulated air traffic control tasks by means of dual frequency head maps. *Frontiers in Physiology, 11*, 300. https://doi.org/10.3389/fphys.2020.00300
Roscoe, A. H. (1984). Assessing pilot workload in flight. In: *AGARD Conference Proceedings Flight Test Techniques*, Paris, France.
Roscoe, A. H., & Ellis, G. A. (1990). *A subjective rating scale of assessing pilot workload in flight: A decade of practical use: A technical report* (TR 90019). Farnborough, Hampshire. Procurement Executive, Ministry of Defence.
Stokes, A., & Kite, K. (1997). *Flight stress: Stress, fatigue, and performance in aviation* (Repr). Avebury.
Tattersall, A. J. (1994). Practical guidelines for workload assessment. In J. A. Wise, V. D. Hopkin, & D. J. Garland (Eds.), *Aviation human factors series. Human factors certification of advanced aviation technologies: Proceedings of Human Factors Certification of Advanced Aviation Technologies Conference held at the Château de Bonas*, near Toulouse, France, July 19–23, 1993 (pp. 193–205). Embry-Riddle Aeronautical University Press.
Tattersall, A. J., & Foord, P. S. (1996). An experimental evaluation of instantaneous self-assessment as a measure of workload. *Ergonomics, 39*(5), 740–748. https://doi.org/10.1080/00140139608964495
Weinger, M. B. (1999). Vigilance, boredom, and sleepiness. *Journal of Clinical Monitoring and Computing, 15*(7–8), 549–552. https://doi.org/10.1023/a:1009993614060
Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159–177. https://doi.org/10.1080/14639220210123806