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# Dealing with unforeseen complexity in the OR: the role of heedful interrelating in medical teams

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Highly complex operations such as paediatric cardiac surgery operations are characterised by many non-routine events. This study looked in detail at 40 paediatric cardiac cases in order to study how a highly competent team deals with the unforeseen complexity arising during these cases. A multi-method approach was used, employing questionnaires and direct team observations. Our results show that this particular team relied to a large extent on explicit coordination processes in order to deal with non-routine events. Non-routine events were strong predictors of explicit coordination processes, even when we controlled for the duration of the operation. Most non-routine events were noticed and dealt with through routine procedures. For dealing with the remaining difficult problems, processes such as heedful interrelating are required.

**Keywords:** teamwork; medical teams; team communication; heedful interrelating; explicit coordination

## 1. Introduction

Research on the development of expertise has shown that expertise is highly dependent on specific domain-knowledge and does not easily transfer to novel situations outside one's domain of expertise (Feltovich *et al*. 2006). When confronted with novel problems outside one's area of expertise, so-called 'first generation' theories of expertise (Holyoak 1991) assume that one has to resort to general problem-solving strategies, as evidenced by this quotation from Chi and Bjork (1991, p. 69):

> Obviously, for nonroutine cases, experts cannot invoke automated perceptual skills that are derived from a rich knowledge base. In these atypical cases, experts must resort to the step-by-step deliberation that novices generally have to undertake, relying on their general strategies rather than domain-specific procedural rules.

However, these 'first-generation' theories of expertise are primarily concerned with routine expertise, or the consistent application of knowledge to well-known situations. Adaptive expertise, or 'heedful performance' (Weick and Roberts 1993) is the ability to apply knowledge flexibly and adaptively to novel and ambiguous situations (Hatano and Inagaki 1986). According to Weick and Roberts (1993, p. 363) '[t]he word "heed" captures an important set of qualities of mind that elude the more stark vocabulary of cognition'. Heedless performance suggests a failure of intelligence rather than a failure of knowledge. It is a failure to see, to take note of, to be attentive to, to be vigilant. Weick and Roberts

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(1993) then extended this idea to groups by describing a process of 'heedful interrelating' that connects sufficient individual know-how to meet situational demands. In fact, they argued that there is little room for heroic, autonomous individuals in high-reliability systems that need to deal with emergency conditions and interactive complexity. In their words, '(. . .) when individual comprehension proves inadequate, one of the few remaining sources of comprehension is social entities' (*ibid*., p. 376). Heedful interrelating is assumed to prevent team members from narrowly following protocols or relying on over-learned responses (Wears and Sutcliffe 2003) and it may help to break habitual routines in novel situations. As such, the concept is a prime example of complex critical thinking.

## 2. Teams dealing with novel situations

Although individual experts may be able to deal with novel situations to a greater or lesser extent, a team's ability to adapt to novel situations is critical and inherent in expert teams (Salas *et al*. 2009). Recent studies have looked at team communication patterns (Stachowski *et al*. 2009) and coordination strategies (Grote *et al*. 2010) in teams dealing with a simulated nuclear power plant crisis, or high and low task load in a cockpit simulator, respectively. Stachowski *et al*. (2009) found that their higher performing nuclear power plant control room crews exhibited fewer, shorter and less complex interaction patterns during the simulated crisis. Although suggestive for the authors' conclusion that effective teams exhibit greater flexibility by employing less patterned interaction, their research design did not include a routine control condition. Hence, their higher performing crews may have employed a less patterned interaction during routine situations as well, and in fact may not have adapted to the simulated crisis. Grote *et al*. (2010) found that cockpit crews adapted their coordination in response to task load and standardisation. Standardisation reduced the need for leadership, whereas more heedfulness was found with high task load. However, no link could be established between heedful interrelating and overall performance. Yet, the positive relationship between task load and heedful interrelating indicates that crews managed to free resources for coordination even under high task load. At the same time, the authors note that the overall level of task load was comparatively low compared to a real emergency situation in the cockpit. Hence, cockpit crews were not confronted with a truly novel situation in this study, even in the high task load condition.

In conclusion, although there has been recent theorising on team adaptability (see also Burke *et al*. 2006) and a few empirical studies on how teams deal with novel situations, some future research needs remain. One issue is that team studies, even with professionals, frequently neglect the longitudinal aspect: teams are observed for relatively brief periods of time, thus ignoring the possibility that teams may develop adaptive strategies over time. Another issue is that teams are frequently studied in simulated environments that do not pose representative tasks in terms of complexity and ambiguity. Most importantly, however, we are still in the beginning stages of understanding how teams deal with novel situations.

## 3. Medical teams

Medical teams are frequently confronted with novel situations (Healey and Vincent 2007, Salas *et al*. 2007). In recent years, the relationship between medical team behaviour and patient outcome has been studied by a number of researchers (De Leval *et al*. 2000, Christian *et al.* 2006, Catchpole *et al.* 2006, 2007, 2008, Mazzocco *et al.* 2009). These studies may be summarised by stating that good teamwork (both in terms of quality and quantity) is associated with fewer adverse events, shorter duration of operations and lower postoperative morbidity. Minor adverse events are mostly compensated for by policies and procedures already in place, major events are mostly compensated for cognitively or by surgical/technical means (Barach *et al.* 2008). However, these studies all suffer from a number of limitations. The first is that all studies are observational in nature, allowing only conclusions to be drawn about associations between teamwork, adverse events and patient outcome. A second limitation in most studies is that observations of teamwork behaviour were made immediately after the operation or at sparse intervals during the operation. In the former case, knowledge of the outcome may have influenced the coding of teamwork behaviour ('hindsight bias', Fischhoff 1975); in the latter case, density of observations of teamwork behaviour was too low to permit conclusions.

An exception is a study by Xiao *et al.* (2003) studying the effects of task urgency on team communication patterns of trauma teams. Although not specifically dealing with novel situations, Xiao *et al.* (2003) found that when task urgency was high, teams would strengthen communications between the team leader and the senior member of the team and reduce communication from the leader to the junior member. Leaders tended to provide more instructions and asked fewer questions when task urgency was high. This result seems to run counter to the study by Grote *et al.* (2010), but perhaps may be explained by the relatively low task load in the latter study compared to the real-life cases studied by Xiao *et al.* (2003).

One of the few medical studies to establish a direct link between adaptive coordination and medical performance, is the study of Manser *et al.* (2009). During a simulated anaesthetic crisis (malignant hyperthermia), they showed that higher-performing anaesthesia teams exhibited less coordination of actions or tasks and more coordination of information during the first 5 min after declaration of the simulated crisis. A more recent study by Burtscher *et al.* (2010) did not find an effect of non-routine events on information coordination in anaesthesia teams, but only on task coordination. This may have been due to the study's focus on common non-routine events rather than on critical but rare events. Hence, although medical teams frequently need to cope with novelty, relatively little research has been carried out on the strategies that these teams employ to deal with novel situations.

## 4. Current study

The aim of the current study was to investigate how a paediatric cardiac surgical team dealt with varying degrees of task complexity over an extended period of time (11 months). We tried to remedy some of the shortcomings of previous studies by making detailed observations of this team in real-time during real-life cases. It should be noted that paediatric cardiac surgery is a specialty with very low error tolerance that encompasses many complex procedures that are dependent on a sophisticated organisational structure, coordinated efforts of multiple individuals, and high levels of cognitive and technical performance (Carthey *et al.* 2001, Gallivan *et al.* 2001, Barach and Johnson 2006). Task demand is always high in these operations and may rise to extremely high levels when highly complicated surgical procedures have to be carried out.

Given that expertise in routine situations is 'recognition-based' (Simon 1981, Klein 1993), we expect a surgical team to exhibit a regular flow of activities consisting of assessing the situation and coordinating actions (e.g. if the activated clotting time of the blood is higher than 480 s, then we may go on cardiopulmonary bypass). This regular flow may be interrupted by adverse events—unintended incidents in care that may result in adverse outcomes or may require additional care efforts to prevent adverse outcomes (Kohn *et al*. 2000). For example, when there are canulation problems, when there are unexpected bleedings, or when the aorta pressure is too low, the team needs to take additional care efforts immediately. Adverse events may require heedful interrelating, support behaviours or problem solving behaviours. As interrelating deteriorates, there is slower correction of errors and more opportunities for minor adverse events to combine and amplify.

## 5. Methods

This study was conducted in the operating room of the paediatric cardiac surgery team affiliated with a children's hospital in The Netherlands. It involved structured observation of personnel (surgeons, anaesthesiology providers, nurses, perfusionists) doing paediatric cardiac surgical procedures. Observed providers consented to be observed. They were informed about the purpose of the study, and were told that all data would be recorded anonymously and that their personal professional skills would never be subject of discussion or reporting. Full IRB ethics approval was obtained beforehand.

We observed a total of 40 operations (19 during the first period; 21 during the second period). Clinical case complexity was measured using the comprehensive Aristotle® risk assessment scoring system (Lacour-Gayet *et al*. 2004). This scoring tool stratifies based on the potential for morbidity, mortality and the anticipated technical difficulty of a given procedure. Patient outcome was determined on the basis of 30-day postsurgical outcome, and classified in three categories: (1) uncomplicated, (2) minor complication, (3) major complications or death.

The team usually consisted of 8–9 personnel, with the OR nurses constituting the largest group. Hence, the team was relatively fixed and stable, although the exact team composition could vary from operation to operation. Patient outcome results from 2008 showed that the team scored a 98.4% survivability rate, substantially higher than the European average of 95.2%. In 2008, the average Aristotle complexity score the team dealt with was 7.0 (European average: 6.7); the case load for the year 2008 was 183. Since the fall of 2009, after the merger with another unit from a different hospital, the case load has more than doubled.

### 5.1. *Pre- and post-procedure questionnaires*

We developed a brief nine-item questionnaire (mini Surgical Team Assessment Record (STAR), based on de Leval *et al*. (2000)), consisting of two separate parts: one to be filled in prior to procedure and one to be filled in immediately after each procedure by every member of the team. Questionnaires were filled in anonymously, in order to increase honesty in self-disclosure. The pre-miniSTAR consisted of the following questions:

(1) have you received, in your opinion, sufficient information about the patient to be operated in a moment?
(2) have you slept well last night?
(3) are you troubled or distracted by any physical or mental concerns that could possibly affect your performance during the operation?

(4) are you concerned about the performance of other team members during this operation?

The post-miniSTAR could be taken as a proxy for patient outcome, as it was filled out immediately after the operation. It consisted of the following questions:

(1) have you noticed that you have done something that had better not been done or done differently, even though this may not at all have lead to potential harm to the patient?
(2) have you noticed that others have done something that had better not been done or done differently, even though this may not at all have lead to potential harm to the patient?
(3) have you noticed that you or others have done something that had better not been done or done differently, and which has occurred before?
(4) the operation was carried out in a pleasant and harmonious atmosphere
(5) have you noticed disturbances or conflicts in the communication among team members?

Pre- and post-miniSTAR scores were averaged within each subteam, and subsequently summed across subteams in order to arrive at a total score for the team as a whole for each operation, with higher scores denoting poorer preparation (pre-miniSTAR) and occurrence of major non-routine events and disturbances (post-miniSTAR).

### 5.2. *Teamwork tool*

A teamwork tool suitable for dealing with the question how teams deal with both routine and novel events was developed. The team processes and their attributes were partly derived from the study by Grote *et al.* (2010), and partly from previous studies on medical teamwork. Hence, the elements in the tool have all been previously validated. In particular, for coding the teamwork aspects, we have drawn upon and slightly modified (because of the multidisciplinary nature of the team) the NOTECHS (Non-technical skills) system (Mishra *et al.* 2009), and the associated ANTS system for coding anaesthetists' non-technical skills (Flectcher *et al.* 2003) and the NOTSS system for coding surgeons' non-technical skills (Yule *et al.* 2006a, b, 2008). The description of the seven-point rating scales themselves was derived from the Observational Teamwork Assessment for Surgery (OTAS©) research instrument (Undre *et al.* 2006). Behaviour was rated along one dimension only, namely whether it hindered or enhanced teamwork. All communications among team members were noted in real time and written down on a scoring form. These communications were classified and rated during the operation, rather than afterwards, in order to avoid hindsight bias.

We distinguish among four main processes, each with several attributes:

Teamwork tool

- Explicit coordination
  - Situation Awareness
  - Coordination
- Heedful Interrelating
  - Noticing and communicating
  - Anticipating

  - Maintaining standards
  - Backup Behaviour
  - Closed-Loop Communication

- Support Behaviours
  - Support of Others
  - Backup Behaviour
  - Relational Communication

- Decision Making
  - Problem Diagnosis
  - Risk Assessment
  - Option Generation
  - Outcome Review

Below, the teamwork process model is elaborated in more detail and illustrated with examples from actual procedures observed.

#### 5.2.1. *Explicit coordination*

Sequences of Situation Awareness and Coordination, indicating standard ways of dealing with routine events. The following conversation between surgeon (S), anaesthetist (A), and perfusionist (P) is an example of an exchange of situation awareness statements and resulting actions (the exchange takes place within a two minute period):

S: 'Is the ACT running?'
A: 'ACT runs'
A: 'Can I give some plasma?'
P: 'Yes'
S: 'Was the ABP too low?'
A: 'Yes'
P: 'I will take the ACT device to our site, ok?'
A: 'Yes'
P: 'ACT is 350 and still running. Suction set is put on'

#### 5.2.2. *Heedful interrelating (or 'mutual performance monitoring', Salas et al. 2005)*

Instances of Maintenance of Standards, Anticipating, Noticing and Communicating, Backup Behaviour and Closed-Loop Communication, indicating keeping track of fellow team members' work to ensure that everything is running as expected and to ensure that they are following procedures correctly by providing corrective responses to non-routine events. For instance, when A1 has inserted the tube for A3, A2 intervenes:

A2: 'That tube is in very deep'
A1: pulls back the tube a little.

Another example occurs when the nurse provides material to the surgeon for a urine catheter:
S (to S3): 'This is a little large for this patient, don't you think?'
N: takes new material for catheter, without being asked for

S: starts urine catheter session without preparation, needs help from others to succeed procedure.

#### 5.2.3. *Support behaviours*

Instances of Support of Others, Backup Behaviour, and Relational Communication, indicating supporting processes, assisting behaviour and maintaining proper team climate. Examples:

N: 'Can you give me a chair to sit on?'
P: provides chair

N: 'Can somebody help me?'
P: helps plugging in the electric saw

A3: 'I saw the vocal cords, but I don't think I can make the turn'
A1: explains and demonstrates how he inserts the tube

#### 5.2.4. *Decision making*

Problem solving and leadership in the narrow meaning of the word, indicating problem diagnosis, risk assessment, option generation and outcome review. For instance:

A1: 'We see ACT rise to 400, like we did not give protamine'
A1: 'We take another blood sample for an ACT'
A1 and S1 discuss the situation with protamine and low ACT values
A1, A2, S1 and S2 subsequently discuss the possibility that something else was given than protamine. A-team thinks this is not possible.
A2 tries to locate the ampoule used to take medication from, but cannot locate it.

### 5.3. *Non-routine events*

We used Weinger and Slagle's (2002) definition of 'non-routine event' adapted from the nuclear power industry, namely: '*any* event that is perceived by care providers or skilled observers to be unusual, out-of-the-ordinary or atypical'. This is a broad definition and includes everything from phone calls, masks not worn properly to serious incidents endangering the patient's condition. This definition is purposefully broader and more neutral than the concept of 'adverse events', that is tainted by the flavour of hindsight bias (not all events are incidents). Non-routine events were scored separately from the teamwork, as events (such as beepers going off) and teamwork (such as dealing with these beepers) are conceptually different. Non-routine events were assessed by the observers during the operation, and corroborated by the team members afterwards, both by asking about non-routine events in the post-miniSTAR questionnaire and by interviewing team members. All non-routine events were categorised afterwards by the main anaesthesiologist in one of the following four categories:

(1) disturbances during the execution of the procedure (e.g. peripheral hand-infuse leaks during flushing; problems to maintain proper saturation)
(2) remarkable individual behaviour, unrelated to the procedure (e.g. eats apple, drinks coffee, does not wear mask properly, arrives too late due to traffic jam)

(3) external events (e.g. pagers, beepers go off, phones ring; no ICU-beds available)
(4) events caused by unpredictable patient factors (e.g. allergies; inflammation of eye)

Non-routine events were also categorised into 'minor' and 'major' events. Major events were problems that were likely to have serious consequences for the course of the operation (e.g. logistical problems with availability of personnel or equipment) or patient outcome. Minor events were all other events.

### 5.4. *Observers and training*

Observers of the surgical procedures were two trained human factors experts. As the training of the observers was discussed at length in another paper (Schraagen *et al.* 2010), we will restrict ourselves to the main points here. Training for the two observers included in-depth directed study of cardiac surgery theory and literature, watching videotaped paediatric cardiac surgery procedures and detailed discussions of ethnographic observational methods. Observers observed at least 10 live cases prior to collecting data. Prior to collecting data, observers had to pass an examination. The exam consisted of watching a 2 h fragment of a videotaped operation, and scoring this fragment in real-time on a minute-by-minute basis. Interrater reliability was assessed by calculating the number of events scored by both observers and determining whether or not observers rated these events identically as far as teamwork was concerned. Interrater reliability was 91% at the level of the four main teamwork categories and 84% at the level of the 14 detailed subcategories. Taking chance into account, Cohen's Kappa was 0.77, which shows a high level of agreement (Robson 2002). Observers were tested two more times during the study: once halfway through the first observation period, in order to assess the stability of their rating, and once at the beginning of the second observation period, in order to assess the maintenance of their observation skills over time. Cohen's Kappa scores were 0.50 and 0.66, respectively. Although somewhat lower, these scores are still acceptable. More importantly, they served as impetus for discussions on establishing explicit criteria for coding teamwork behaviour.

## 6. Results

In terms of absolute frequencies, explicit coordination occurred most often, followed by heedful interrelating, support behaviours and decision making. The latter category was observed too infrequently for perfusionists and nurses to take into account in further analyses. Also, heedful interrelating and support behaviours were combined for these two specialties into an overall category 'mutual performance monitoring/backup behaviours' (cf. Salas *et al.* 2005), in order to obtain sufficient frequencies. Table 1 shows the overall means, across all operations, for the four different subteams. From the table, it is clear, as displayed by the lack of overlap between the 95% confidence intervals, that relative to anaesthetists, surgeons display more explicit coordination behaviour, whereas anaesthetists display more heedful interrelating, relative to surgeons.

Table 2 shows the correlation matrix between all relevant measures.

### 6.1. *Relations between team processes and patient outcomes*

A relation between the three patient outcome categories and teamwork behaviours was calculated, in order to establish a link between team processes and team outcomes. It should be noted (Table 2) that more complex operations tended to last longer

Table 1. Means, standard deviations (SD) and 95% confidence intervals for the four teamwork processes for each of the four subteams (surgeons, anaesthetists, perfusionists, nurses).

| Teamwork process | Explicit coordination | | | Heedful interrelating | | | Support behaviours | | | Decision making | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subteam | Mean (SD) | 95% CI lower | 95% CI upper | Mean (SD) | 95% CI lower | 95% CI upper | Mean (SD) | 95% CI lower | 95% CI upper | Mean (SD) | 95% CI lower | 95% CI upper |
| Surgeons | 21.05 (13.89) | 16.55 | 25.55 | 6.85 (5.76) | 4.98 | 8.71 | 3.77 (2.95) | 2.81 | 4.73 | 0.85 (1.27) | 0.43 | 1.25 |
| Anaesthetists | 15.33 (7.95) | 12.75 | 17.91 | 9.28 (5.65) | 7.45 | 11.11 | 3.61 (3.25) | 2.56 | 4.67 | 1.05 (1.83) | 0.46 | 1.65 |
| Perfusionists | 11.31 (7.87) | 8.75 | 13.86 | Mean (SD) | | | 95% CI lower | | 95% CI upper | – | – | – |
| | | | | 3.13 (1.89) | | | 2.51 | | 3.74 | | | |
| Nurses | 3.31 (3.04) | 2.32 | 4.29 | 2.95 (3.74) | | | 1.74 | | 4.16 | – | – | – |

Table 2. Correlation matrix between relevant measures.

| | Aristotle | Pre-miniSTAR | Non-routine events | Operating time (min) | Total NOTECHS | NOTECHS per min | Post-miniSTAR | Outcome |
|---|---|---|---|---|---|---|---|---|
| Aristotle | 1.00 | −0.01 | 0.08 | 0.74** | 0.39* | 0.04 | 0.54** | 0.51** |
| Pre-miniSTAR | | 1.00 | 0.10 | −0.02 | −0.09 | −0.09 | 0.03 | −0.14 |
| Non-routine events | | | 1.00 | 0.44** | 0.18 | −0.03 | 0.31* | 0.30* |
| Operating time (min) | | | | 1.00 | 0.45** | −0.03 | 0.62** | 0.61** |
| Total NOTECHS | | | | | 1.00 | 0.87** | 0.33* | 0.27 |
| NOTECHS per min | | | | | | 1.00 | 0.07 | 0.01 |
| Post-miniSTAR | | | | | | | 1.00 | 0.56** |
| Outcome | | | | | | | | 1.00 |

Note: * and ** indicate significant correlation at $p < 0.05$ and $p < 0.01$ (2-tailed), respectively.

($r = 0.74$, $p < 0.01$) and tended to result in more negative patient outcomes ($r = 0.51$, $p < 0.01$). Also, longer operations were associated with more instances of observed team behaviours ($r = 0.45$, $p < 0.01$). Therefore, frequencies of team processes, in general, are expected to be associated with patient outcomes through the intermediate variable of duration of operation. However, for our purposes, the interesting question was whether all four types of team processes were associated with patient outcome, or whether this relation was restricted to particular types of team processes. Results from ANOVAs showed that, with all three outcome categories taken into account, only explicit coordination processes of the anaesthetists differed significantly across the three outcome categories, $F(2, 36) = 4.78$, $p = 0.01$ ($M_{uncomplicated} = 12.88$; $M_{minor\ complications} = 21.55$; $M_{major\ complications} = 16.40$).

In order to control for duration of operations, we calculated ratios of heedful interrelating, support behaviours and decision making, relative to explicit coordination. We expected that when minor complications or major morbidity would occur, task load would increase and we would see increases in heedful interrelating, support behaviours and decision making, relative to explicit coordination. However, none of the ratios differed significantly for the three outcome categories, indicating that when we control for increases in explicit coordination, the other three processes do not increase with worsening patient outcomes.

### 6.2. *Relations between team processes and non-routine events*

Regression analyses were conducted with the four team process categories as dependent variables and the four categories of non-routine events as predictors. In this case, we controlled for duration of the operation directly by dividing the number of teamwork behaviours by the time in minutes that the operation lasted. Only explicit coordination was related to various kinds of non-routine events. For anaesthetists, this process could be significantly predicted by events associated with individual behaviour (adjusted $R^2 = 0.09$, $F(1, 37) = 4.73$, $p = 0.04$). For nurses, this process could be significantly predicted by events associated with individual behaviour and disturbances during the execution of the procedure (adjusted $R^2 = 0.16$, $F(2, 36) = 4.52$, $p = 0.02$), and also when patient-related factors are included (adjusted $R^2 = 0.15$, $F(3, 35) = 3.20$, $p = 0.03$). For surgeons and perfusionists, explicit coordination was not significantly related to non-routine events. In conclusion, for two of the four specialties, the number of explicit coordination statements per minute could be significantly predicted by various categories of non-routine events.

### 6.3. *Qualitative analysis*

In order to complement the quantitative analysis, we carried out a qualitative analysis on a number of selected cases. Given the importance of case complexity, we selected four cases: two of high complexity (average Aristotle-index: 11.5), and two of low complexity (average Aristotle-index: 4.5). We crossed these two levels of complexity with type of outcome as determined by the post-MiniSTAR questionnaire: a 'good' outcome was defined as a score below the 95% CI (2.28), whereas a 'poor' outcome was defined as a score above the 95% CI (3.93). The two cases with a good outcome received an average score of 1.5, whereas the two cases with a poor outcome received an average score of 6.2. For the present purposes, we were primarily interested in the highly complex cases, as these might present evidence for the importance of heedful interrelating, decision making and support behaviours.

The case with the poor outcome was characterised by two major events: a wrong BSA value noted on the white board before the operation, and a cannulation problem (wrong connection piece for the canula). The wrong BSA value was probably due to lack of proper checking, but was caught before the operation started by the surgeon. The cannulation problem was not caught beforehand but had to be dealt with during the operation. Interviews afterwards revealed that this problem was most likely due to a problem with the hospital's ordering system. The case was further characterised by many minor non-routine events (distractions due to pagers, beepers; perfusion difficulties; workspace management failures, such as the surgeon almost slipping off the bench he stood on). The operation lasted for 373 min and the team received an average teamscore of 3.35.

The case with the good outcome was characterised by many instances of heedful interrelating and support behaviours (decision making occurs too infrequently as a category to base useful conclusions on). Below, a few examples are provided of team communication indicating heedful interrelating.

#### 6.3.1. *Noticing and communicating*

- 'Is that light dimmed on purpose?'
- 'He is all cold peripherally'
- 'Oh, this suction device makes that noise'
- S: 'I have a bleeding, but I don't see where. It isn't going any better'

#### 6.3.2. *Anticipating*

- P: 'Shall I give him a little filling to increase the pressure?'; A: 'I am already doing that'
- S: 'Is A1 still here?'; A3: 'No, but you want to ventilate?'
- S: 'Can we lower the pressure a little bit?'; A1: 'I already did that'

#### 6.3.3. *Maintaining standards*

- Replaces reservoir suction set
- 'There needs to be a cap on this' N2 provides cap.

#### 6.3.4. *Backup behaviour*

- 'Can you give me a chair to sit on?'
- 'Can somebody help me plug in the electric saw?'

#### 6.3.5. *Closed-loop communication*

- 'Heparine; yes, I have heard you'
- 'Is the ACT running?' 'ACT runs'
- 'I will take the ACT device to our side, OK?' 'Yes'
- S: 'Cooling towards 24 degrees' P: 'Cooling towards 24 degrees'

- S: 'Flush cardioplegia'; P: 'Flush cardioplegia'. 'Plegia flush? Plegia is being flushed'

The operation lasted 348 min and was of even higher complexity than the comparable case that resulted in a poor outcome. Number of non-routine events was only nine, compared to 26 in the comparable case. Teamwork was rated with 3.87, substantially higher than the 3.35 of the comparable case.

## 7. Discussion

Highly complex operations such as paediatric cardiac surgery operations are characterised by many non-routine events, some due to unpredictable patient physiology, some to individual behaviour, some to external events and some due to procedural difficulties. In a few cases, major events occur that, if uncompensated by the team, may result in major morbidity or even death (de Leval *et al.* 2000). Our study has looked in detail at 40 paediatric cardiac cases in order to study how a highly competent team deals with the unforeseen complexity arising during these cases. Our results have shown that this particular team relied to a large extent on explicit coordination processes in order to deal with routine events. Non-routine events were also strong predictors of explicit coordination processes (for anaesthetists and nurses), even when we controlled for the duration of the operation. Explicit coordination processes, in turn, were related to patient outcomes, but this result may have been partly due to the increase in duration of the operation with worsening patient outcome, and hence a concomitant increase in quantity of observed explicit coordination behaviours. We found that when we controlled for duration of operation, processes such as heedful interrelating did not increase with worsening patient outcomes.

However, this quantitative approach may have missed the impact of processes other than explicit coordination. Although heedful interrelating, support behaviours and decision making occur less frequently than explicit coordination, they may be no less important, particularly in difficult cases. We therefore also analysed the data qualitatively and found suggestive evidence for a difference in teamwork in two cases of comparable difficulty. The difficult case resulting in poor outcome (as indicated by the team members themselves immediately afterwards) was characterised by lack of anticipation and insufficient cross-checking of information and materials. Approximately the same team, nine months later, dealt with an even more complex case in a much more attentive fashion, employing processes such as anticipation, noticing and communicating what is noticed, maintaining standards, backup behaviour and closed-loop communication. Although we cannot claim any causal connection, these teamwork behaviours were rated higher by independent observers, as yet unaware of the outcome, and fewer non-routine events were observed. In both cases, interrelating went on, but in the first case it was done with indifference and carelessness, whereas in the second case it was done heedfully.

In conclusion, the concept of heedful interrelating seems promising for explaining differences in team performance in healthcare teams. However, heedful interrelating does not provide a complete picture of teamwork in the setting studied. Our quantitative results clearly indicated the importance of explicit coordination mechanisms in dealing with non-routine events. This implies that most non-routine events are noticed and dealt with through routine procedures (see Burtscher *et al.* 2010, for similar results). For dealing with the remaining difficult problems, processes such as heedful interrelating are required.

Dealing with the unknown successfully may pave the way for dealing with the known successfully: adaptive expertise lets intuitive expertise run its course.

### 7.1. *Limitations*

This study was limited insofar as it studied one particular team in one particular medical specialty: paediatric cardiac surgery. Objective performance results have shown that this particular team has higher than average patient survivability rates while at the same time carrying out more complex operations on average than other European paediatric cardiac surgical teams. The team may therefore not be representative for teams in this field, and our results certainly do not generalise to more standard types of operations, let alone to other types of teamwork, such as handovers between different organisational units within or between hospitals. Yet, we would expect the same methodology to be applicable to observe and rate teamwork.

Although communication was noted down in real-time, which afforded significant advantages, observing and rating teamwork for eight or nine individuals at the same time, proved to be a challenge for our observers. Due to time and privacy restrictions, we could not resort to video-analysis afterwards. This implies that our level of analysis was by necessity somewhat cruder than if we had been able to analyse the conversations on a word-by-word basis. It is also quite possible that we missed some of the details of the interactions, including the important non-verbal interactions. It is, however, fair to note that video recordings also have their limitations in terms of restricted point-of-view and limited audibility of speech due to masks being worn in the OR setting.

Because of the observational nature of our research, we cannot draw cause-and-effect relationships between teamwork processes and patient outcome measures. This is the price to pay for observing real teams in real-life circumstances (high complexity, high workload). We did, however, use the theoretical concepts established under controlled experimental conditions in the development of our coding scheme.

### 7.2. *Directions for future research and practical implications*

This research, together with the recent research carried out by Grote et al. (2010), is one of the first to operationalise and empirically observe the concept of 'heedful interrelating'. Although this concept seems promising, it definitely needs further theoretical and empirical development. For instance, as heedful interrelating is an attention-demanding process, would it not be the first to suffer in demanding situations? The process may also be highly variable, both within teams and across teams (Weick and Roberts 1993). What is the nature of this variability? How is heedful interrelating being maintained in teams, and how is it renewed during resocialisation? Weick and Roberts (1993) suggested that heedful interrelating is conveyed by oldtimers to newcomers through vivid stories and exemplary behaviour. This, together with the notion that heedful performance is not habitual performance, nor the outcome of drill and repetition, suggests that it cannot be easily taught through CRM training, except by raising awareness. Ironically, this is one of the weaker forms of team training (Salas *et al*. 2008), and the predominant aspect CRM training is being assessed on (Salas *et al*. 2006). A more promising alternative may be to focus on 'video-reflexive ethnography' (Carroll *et al*. 2008), in which selective video footage is shown to clinicians for feedback, leading to significant changes in behaviour. It would be very interesting to use this method in fostering heedful interrelating in the OR.

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