Assessing blood loss in clinical practice

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Abstract

Postpartum haemorrhage is a major global cause of mortality and morbidity amongst childbearing women. Failure or delay in recognising the severity of bleeding is an important contributory factor in these outcomes. Earlier recognition of haemorrhage would facilitate earlier intervention and treatment, helping resolve the causes of bleeding sooner, and thereby improving outcomes for women. Ways to achieve earlier recognition have traditionally focussed on the clinical skill of assessing the volume of blood loss. However, despite extensive research, the optimum method of assessing blood loss and achieving earlier diagnosis remains unclear. Examination of the psychological literature suggests that clinical decision-making is more complex and highlights some of the reasons why traditional approaches have had a limited effect. Using psychological theories of decision-making to inform solutions may lead to more successful strategies to address the issues than the current focus on volume assessment of blood loss.

Keywords: Blood loss assessment; Postpartum hemorrhage; Diagnosis; Recognition; Clinical decision-making; Psychological theories

Introduction

Postpartum haemorrhage (PPH) is the leading cause of maternal deaths globally, and severe PPH is increasing in high-income countries [1]. In the United Kingdom (UK) and Ireland, PPH is the second leading cause of direct maternal death and the leading cause of severe maternal morbidity [2,3]. Factors believed to contribute to the severity and outcomes associated with PPH include failure to recognise the extent and effects of haemorrhage [4]. The most recent report of the UK and Ireland Confidential Enquiries into Maternal Deaths and Morbidity [3] highlighted that the women who survived severe haemorrhage had earlier recognition and resolution of their bleeding than the women who died. This suggests that accurate judgements about the extent of blood loss, alongside an appreciation of the physiological effects, are important factors for influencing outcomes in women who experience haemorrhage. Visual estimation is described as the universal method for assessing blood loss and diagnosing PPH [5], particularly following vaginal delivery [6]. However, the inaccuracy of the method is well documented [7]. Researchers have focused on ways to improve clinical skills in visual estimation as a pre-requisite to more timely PPH diagnosis, but despite these efforts, delayed recognition is a persistent theme. This chapter will explore current approaches to assessing maternal blood loss and consider these in context with psychological theories of decision-making.

Normal blood volumes

The normal blood volume of a non-pregnant adult is around 70 millilitres (ml) per kilogram (kg), equating to almost 5 L of blood in a 70 kg adult [8]. The 48% increase in blood plasma volume during pregnancy [9], along with other physiological changes to the cardiovascular system, means that women ~~can~~ may be able to tolerate losing up to 35% of their circulating blood volume before becoming symptomatic [10]. With around 500 ml of maternal blood flowing through the placental bed each minute by the end of pregnancy [11], women have the potential to lose large volumes of blood rapidly during childbirth. However, physiological mechanisms that work simultaneously during the third stage of labour mean that any blood loss associated with it is usually of short duration, self-limiting and, in the majority of women, is well tolerated [5].

Volume definitions of excessive blood loss and PPH

The traditional volume threshold of blood loss used to define primary PPH is ‘500 ml or more from the genital tract within 24 h of childbirth’ [12]. In the UK, the Royal College of Obstetricians and Gynaecologists (RCOG) [13] differentiates primary PPH as minor (500–1000 ml) or major (more than 1000 ml); with major PPH being further described as moderate (1001–2000 ml) and severe (more than 2000 ml). This reflects the view that blood losses of up to 1000 ml can be tolerated by most women, with deterioration and tissue damage most likely to occur at volumes in excess of 1500 ml [13]. These thresholds imply that an accurate estimation of the volume of blood loss is critical for identifying women at risk of hypovolaemic shock and for guiding the timing of interventions to prevent or minimise the physiological effects [14]. However, if visual estimation of blood loss volume is imprecise, predicting when tissue damage and irreversible shock will occur will be difficult to determine. Moreover, if total blood volume varies in relation to body mass index [8], using arbitrary volume thresholds to define and treat PPH may put women at risk. The increased risk of maternal death from haemorrhage in women weighing less than 60 kg has emphasised this problem [15] leading experts to suggest that a single universal volume definition of PPH is neither safe,~~ and~~ possible, nor desirable [16]. Using different definitions for different purposes, such as treatment, audit and~~,~~ research, may facilitate more informative evidence generation and synthesis and present more practical solutions for use in practice [16].

Visual estimation of the volume of blood loss

In the 1950s and 1960s, a series of studies [17–21] used laboratory methods to determine average blood loss at different types of birth. The methods were useful for exploring individual variations of blood loss, establishing the time of greatest ~~blood~~ loss and assessing the effects of oxytocic drugs. The studies also established the inaccuracy of visual, volume estimation, reporting overestimation of low volumes of blood loss and underestimation of larger volumes. Various studies have since confirmed that health professionals are highly inaccurate at estimating blood loss volume, regardless of their level of training and experience [7].

Experts are cautious about recommending specific methods of assessing blood loss, because of a lack of evidence of their efficacy [13]. A recent Cochrane review [22] confirmed a lack evidence for recommending specific methods for use in practice and suggested a need for randomised controlled trials that correlate blood loss volumes with relevant clinical outcomes. One of the two studies included in the Cochrane analysis compared the use of calibrated blood collection bags to visual estimation and evaluated their impact on the timing of blood loss-related interventions and incidence of severe PPH [23]. The cluster randomised controlled trial included 25,381 vaginal births, in 78 maternity units, in 13 European countries. Blood collection bags increased the accuracy of volume estimates compared to visual estimation but did not impact the timing of PPH diagnosis, or prevent progression to severe PPH. The researchers concluded that ‘having a more accurate assessment of blood loss is not in itself sufficient to change behaviours of care givers and improve the management of PPH’ [23] (p6). However, the behaviour of the clinicians using the blood collection bags was not explored, therefore, the reasons for these outcomes remains unclear. Furthermore, blood collection was usually discontinued at the end of third stage management, once the birth attendant was no longer concerned about blood loss. This means that assessing the usefulness of the tool for calculating on-going, insidious blood loss, was not evaluated.

Alternatives methods of assessing blood loss

Methods to determine a woman's physiological response to blood loss are often advocated as adjuncts or alternatives to volume assessment [24,25]. Those most commonly used, or being considered for use in practice, will be discussed here.

Early warning scores

The use of early warning scores (EWS) alongside physiological monitoring are recommended for facilitating earlier recognition of women with impending critical illness and collapse [24]. Most maternity providers in the UK now use modified obstetric EWS tools [25] despite conflicting views of their efficacy [26]. EWS involve scoring each parameter of vital signs monitoring (usually temperature, pulse, blood pressure, respiratory rate and conscious level), with the aggregate score determining the need for closer monitoring, intervention and review. Although a standardised EWS system is available for general adult inpatients in the UK [27], this is not validated for use with childbearing women.

To validate the EWS exemplar provided in the UK confidential enquiry report [24], Singh and colleagues [28] tested the tool with 676 patients. They found that it had a high sensitivity (89%) and specificity (79%) but a relatively low positive predictive value (39%), for detecting maternal morbidity. The authors concluded that the chart was useful for predicting obstetric morbidity and should be used routinely in every obstetric unit, to facilitate early detection of acute illness. However, further work to improve the positive predictive value of the tool was also recommended.

Carle and colleagues [29] designed and validated an aggregate weighted, obstetric EWS which proved highly sensitive for discriminating survivors from non-survivors in a critical care dataset. Due to the specific nature of this population, the authors acknowledged that their work would not readily translate to the general maternity population and that further work was required to determine the most sensitive parameters for use in this group of women. Research to evaluate the role of the tools for preventing maternal morbidity is still required [25].

The effectiveness of EWS tools inevitably depends on the accuracy of measuring, recording and scoring the physiological parameters, calculating the aggregate score, and responding appropriately to deviations from the normal range [27]. Other limitations relate to their acceptability and use in practice. An ethnographic study which explored this looked specifically at staff perceptions of the value of EWS in managing maternal complications in the peri-partum period [30]. Staff valued the framework EWS provided for discussion and escalation of care across hierarchical and occupational boundaries, promoting uniformity of care for acutely ill patients. They also appreciated the expertise of the critical care outreach teams whose staff provided an educational resource and 'an extra pair of hands'. However, there were some reservations that EWS might inappropriately medicalise childbirth. Both obstetricians and midwives agreed that during one-to-one support, the midwife would be able to identify changes in the woman's clinical condition, without an EWS chart. Similarly, during postnatal care, midwives often used their professional judgement to give lower priority to vital signs monitoring than other postnatal activities. The authors concluded that selective use of EWS limited the benefits of the tool and reduced its value as a universal safety net for detecting deterioration. It has therefore been ~~This~~ suggest~~s~~ed that these tools should be seen as adjuncts to existing methods of identifying deterioration, rather than failsafe mechanisms in their own right [25].

The compensatory mechanisms of hypovolaemic shock

Recognising deterioration in childbearing women can be challenging due to maternal physiological adaptation to pregnancy [13] and the compensatory mechanisms of shock. The ~~(~~compensatory~~)~~, negative feedback mechanisms, work to maintain cardiac output and arterial blood pressure, in the early stages of hypovolaemic shock, preventing serious damage to the tissues [31]. Understanding the pathophysiology of the compensatory mechanisms, and recognising the subtle clinical signs and symptoms associated with their deployment (Table 1) may be another way of assessing blood loss and its effects [31]. Current biophysical bedside testing devices have limited ability to measure these subtle changes, but these could be developed in the future. Another approach is to use standard vital sign measurements but combine results to amplify any changes. One example of this is the 'shock index'.

Table 1 Homeostatic responses to shock – negative feedback mechanisms that can maintain/restore normal blood pressure during hypovolaemic shock [31].

alt-text: Table 1

System	Activation	Response	Effect	Outcome	Clinical Presentation
Kidneys	Reduced blood flow	Renin secretion initiates the renin-angiotensin-aldosterone system.	Vasoconstriction. Adrenal cortex secretes aldosterone. Increases renal absorption of sodium and water.	Increased vascular resistance and blood volume.	Blood pressure is maintained.
Posterior pituitary gland	Decreased blood pressure	Secretion of antidiuretic hormone.	Enhances water reabsorption by the kidneys.	Remaining blood volume conserved. Vasoconstriction increases systemic vascular resistance.	Thirst is caused by loss of extracellular fluid. Urine output reduces.
Aortic and carotid baroreceptors	Decreased blood pressure	Sympathetic responses: marked vasoconstriction of arterioles and veins of the skin, kidneys and other abdominal viscera.	Vasoconstriction of arterioles increases systemic vascular resistance. Constriction of the veins increases venous return.	Adequate blood pressure maintained. Sympathetic stimulation increases heart rate.	Cool, pale and clammy skin due to constriction of skin blood vessels and sympathetic stimulation of sweating. Nausea may be experienced due to impaired blood flow to digestive organs.
Adrenal medulla	Sympathetic response	Increased secretion of epinephrine and norepinephrine.	Vasoconstriction intensified and heart rate increases.	Vasoconstriction, increased heart rate and contractility.	Blood pressure is maintained. Resting heart rate increases but is weak.
				Increased local blood flow may restore oxygen	

Cells	Hypoxia	Vasodilators released (potassium, hydrogen, lactic acid, adenosine and nitric oxide).	Dilates arterioles and relaxes pre-capillary sphincters.	levels in some parts of the body. Vasodilation decreases systemic vascular resistance, which lowers blood pressure.	Blood pH is low (acidosis) due to build-up of lactic acid. Mental state altered due to reduced oxygen supply to the brain. Systolic blood pressure less than 90 mmHg.

If blood volumes falls below a critical level, or if the heart cannot sufficiently restore blood pressure, the compensatory mechanisms will fail to maintain adequate blood flow to the tissues. At this point, shock becomes life-threatening as the damaged cells start to die.

Shock index

Several authors [5,32,33] have examined the use of the ‘shock index’ (calculated by dividing heart rate by systolic blood pressure) to measure the physiological impact of blood loss in childbearing women. A systematic review [5] exploring the relationship between blood loss and clinical signs in non-obstetric populations, found that there was substantial variability in the relationship between physiological observations and blood loss, but a statistically significant association between the shock index and blood loss. Further research in an obstetric population was recommended.

In a retrospective study, the vital signs of 233 women, recorded in the hour after recognition of PPH greater than 1500 ml [33], were used to determine the predictive value of the shock index. The authors reported that the shock index compared favourably with conventional vital signs in predicting intensive care unit admissions and other morbidity outcomes. They concluded that their study was ‘the first to evaluate the predictive ability of shock index in PPH, according to multiple clinical outcomes’ (p271). However, because this was a retrospective study which calculated the shock index for women with known major PPH, the claims relating to the predictive ability of the shock index should be viewed cautiously.

A more recent prospective, pragmatic, stepped-wedge cluster randomised controlled trial [32], introduced a training package and an automated device for measuring blood pressure and pulse during routine maternity care, across Africa, India and Haiti. The automated device calculated the shock index and used a traffic light system to alert healthcare providers of the need to escalate care. There was a significant reduction in one of the primary outcomes (emergency hysterectomy), but no significant reduction in eclampsia or maternal death. Due to the significant differences between and within the clusters, the authors were unable to ~~rule out~~determine the benefit or harm of the intervention.

Fibrinogen assessment

In the UK, it is recommended that women who are actively bleeding have regular assessment of their fibrinogen levels to ascertain whether continued bleeding is the result of disordered clotting and to guide the management and replacement of blood and clotting factors [34]. Since laboratory testing is relatively slow, point-of-care testing, combined with a locally agreed treatment algorithm, is advocated in the maternity setting [13,34]. Details of the bedside clotting assessments are covered elsewhere in this issue.

Decision-making during blood loss

Many strategies introduced for assessing blood loss and to support PPH diagnosis appear to assume that decision-making is a linear process, with an estimation of blood loss volume as the leading component (Fig. 1). However, qualitative research in low-resource settings raised questions about this theory [7,35–37]. The studies found that, while quantification was used to guide management of blood loss, initial reactions were more likely to be responses to the speed and nature of visible blood flow and the physical condition of the woman. More specifically, ‘experience’ was found to be important for informing perceptions of whether blood loss was ‘more than usual’ and for recognising the signs and symptoms of shock [38]. A recent exploratory, mixed-methods study conducted in the UK (The REACT Study) [39], explored blood loss related decision-making in a high-resource setting and observed similar results. Initial responses to bleeding largely involved an automatic reaction to the speed and visibility of blood loss. Volume estimation was generally used retrospectively, after a PPH diagnosis had been made, to guide and justify ongoing decisions. Other important factors affecting decision-making included the physical effects of blood loss on the woman and health professionals' level of professional experience. Considering these findings through the lens of decision-making theory may provide a useful insight into the decision-making processes associated with blood loss assessment and PPH diagnosis and for informing the development of strategies to support the process.

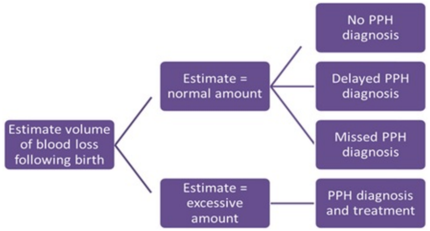

Fig. 1 Assumed linear process of PPH diagnosis.

alt-text: Fig. 1

Models and theories of decision-making

Psychologists use three models to study and explain decision-making [40]. Normative models typically involve applying an equation or algorithm to a decision problem, usually in experimental conditions. Prescriptive models inform the design of improvement interventions, which are often educational. Descriptive models explain how decisions are made in real-world settings and can also help to explain non-adherence to normative models and whether judgements and decisions can be improved.

Descriptive model – dual process theory

Descriptive models are psychological theories that explain how decisions are made in real-world settings and are therefore useful for exploring assessment of, and decision-making during, childbirth-related blood loss. A number of descriptive models exist, but dual process theory is the dominant model in decision-making science [40] and is suitable for exploring clinical prognostic decision-making [41]. Dual process theory describes two processes of cognition, referred to as System 1 and System 2 [42,43] (Table 2). While the two systems operate simultaneously, System 1 is considered to be the primary, default system of decision-making [43,44], operating continuously and automatically, with little or no effort or voluntary control. System 2 is normally in standby mode, with only a fraction of its capacity engaged [43].

Table 2 The dual process theory of reasoning and decision-making [42,43].

alt-text: Table 2

System 1 (S1) automatic primary (default) system	System 2 (S2) effortful activated when S1 encounters a novel or surprise stimulus
Operates continuously and automatically with little or no effort or voluntary control.	Normally in standby mode with only a fraction of its capacity engaged.
Evolutionary, innate capability. (Cognitive optimisation procedures operate at the sub-personal level).	Normative, rule-following rationality. (Cognitive optimisation procedures operate at the personal level).
Automatic, largely unconscious processing.	Controlled, methodical processing of problems, using analytic, computational intelligence.
Relatively undemanding of computational capacity.	Computationally costly, logical mechanisms.
Interactional intelligence relating to pre-conscious processes. Ability to model other minds and read intention.	Analytic intelligence (will override the interactional intelligence of System 1 in individuals with higher cognitive ability).
Construction of situations is highly contextualised, personalised and socialised.	The more controlled processes decontextualise and depersonalise problems.
Automatic contextualisation of problems.	Problems can be dealt with/without social context. Representation is more in terms of rules and underlying principles.
Biases inherent in this system are universal and shared by all humans.	System 2 activated when System 1 encounters a problem, such as a novel situation or a surprise stimulus.

System 1, automatic decision-making

Although there is a dearth of research exploring decision-making during blood loss, that which is available appears to suggest that System 1 (rapid, automatic and intuitive) decision-making is the primary system used to assess blood loss and diagnose PPH. An important finding of the REACT Study [39] was that automatic responses to blood loss varied in sophistication between participants. Women, birth partners and inexperienced health professionals described experiencing a simple, gut-feeling that something was wrong. Delayed recognition of PPH was often attributed to junior staff who focused on one task at a time, often missing more subtle presentations of blood loss. The most experienced midwives and obstetricians described interpreting a range of subtle cues to make automatic, intuitive decisions, which they believed were informed by their past experiences. Many p~~P~~sychologists agree that intuitive judgements are the result of System 1 activity in that they are automatic, arise effortlessly, and often come to mind without immediate justification [44]. However, there are important differences between the origins and operations of intuitive judgements: those that originate from specific prior experience (which are usually highly skilled and accurate) and those that originate from simplifying heuristics (mental shortcuts or ‘rules of thumb’) [45]. Heuristic-based decisions are less accurate and are prone to systematic biases [44]. Cioffi and Markham [46] confirmed that midwives used heuristics to simplify their decision-making and enable a rapid form of reasoning during antepartum haemorrhage. Memories of past cases were used to estimate the probability of the likelihood of certain outcomes. However, they found that because heuristics reduced the number of possible outcomes that were considered by decision-makers, the correct solution to the clinical problem may have been the one that was ignored.

System 2, effortful decision-making

System 2 is activated when System 1 encounters a problem, such as a novel situation or a surprise stimulus. System 2 then searches the memory for a matching situation to help make sense of the surprising event and to support more methodical and specific processing of the problem [43]. The REACT Study [39] found that System 2 decision-making was most often employed after excessive blood loss had been recognised, and by inexperienced staff. This type of decision-making was characterised by more deliberate, methodical and time-consuming processes, such as weighing blood loss and recording physiological observations, and also included applying rules and principles to the management of on-going blood loss.

Expert, intuitive decision-making

Research has confirmed the fundamental importance of experience in developing the skills required for ~~System 1,~~ expert, automatic, intuitive decision-making [47,48]. It is suggested that different methods of decision-making will be used at different stages of professional development (Table 3), with ‘competence’ taking around 2–3 years of ~~postregistration~~ post-registration experience to develop [48]. Magnetic resonance imaging scans of expert and amateur chess players have confirmed that ‘different mechanisms of brain processing and functional brain organisation’ are used at different levels of expertise [49]. This results in expert chess players automatically recognising complex patterns stored in their memory [50], enabling them to identify complex moves which less experienced players do not even consider [44].

Table 3 Decision-making skills and requirements at the five stages of professional development [42–44,47,48,56,60].

alt-text: Table 3

	Novice to expert decision-making continuum:				
Decision-making characteristics	Stage 1 Novice	Stage 2 Advanced beginner	Stage 3 Competent	Stage 4 Proficient	Stage 5 Expert
Development of decision-making skills	Practical tasks are separated into context-free elements with associated rules.	Develops understanding of the context underpinning rules and tasks. Begins to recognise similarities from past experiences.	Large numbers of cues can be recognised and their importance and relevance determined. **Competence takes 2–3 years of experienced practice to develop.**	Recognition is through the use of maxims*, holistic perception and pattern matching. (*the unintelligible nuances in a situation)	Intuitive judgment develops from specific clinical experiences and skills.
System of decision-making	Novice follows rules, checklists and examples of best practice.	Focus is on recognising similarities with past experiences and remembering	Conscious, deliberate reasoning is used to decide which rules to adopt.	Situations are matched to brain-stored, experience-created, situations. A mismatch	Blend of intuition and analysis. Does not rely on rules. Able to make subtle and refined discriminations.

		and following rules.	Mental shortcuts (heuristics) simplify decision-making but are prone to bias and error.	between current situation and expectation triggers a reassessment or new **'Situation Awareness.'** Reaction is through rule-following.	
Development	Direct instruction and feedback required.	Recognition of cues develops under guidance and from experience. Inability to discriminate importance of cues and absorb new details.	Engagement with the emotional consequences of decisions strengthens or inhibits perspectives.	Experience is needed to interpret situations and react automatically.	Wide and varied experiences of situations and responses lead to maintenance and development of decision-making that is automatic and subconscious.
Requirements for development	Direct instruction and feedback.	Support, experience and feedback.	Experience and feedback are essential for learning and storing patterns and cues.		
Limitations	Minimal understanding of context prevents use of discretionary judgment. Rule-following often leads to poor performance in practice.	Recognition of cues and associated rules requires considerable effort, limiting the ability to absorb extra details in new situations.	Seeking the safety of rule-following may inhibit development. In-service training is often focused at this level.	When there is no stored mental pattern or situations are matched to the wrong pattern, there will be no recognition. May continue to follow rules and maxims.	Overconfidence bias and fixation error can reduce use of analytic decision-making by experts.

Cognitive pattern-matching

The~~is~~ view of intuitive decision-making as 'pattern recognition' [50] informed the field of 'naturalistic decision making' (NDM), which used the Critical Incident Technique [51] to study cues used by expert fire commanders to make rapid, intuitive decisions in extreme, time-pressured and life-threatening situations [52]. Rather than using time-consuming, conscious deliberation of alternative options, experts used a blend of intuition and analysis to make fast, automatic decisions, based on experience. Current situations were unconsciously matched to previous events that had been compiled, merged and stored in the memory; with automatic selection of the most plausible course of action [44]. Situations were referred to by the fire commanders as 'typical', implying that matching to a prototype, or mentally archived pattern, was occurring. New situations, where there was no mental match, were recognised as anomalous. This process, described as 'situational awareness', required a high level of perceptual learning and resulted in decision-makers reassessing the situation and considering alternative plans of action. NDM research has been pivotal in advancing the field of 'human factors' [53], which improves performance by combining psychology and engineering to design technologies, processes and work systems that improve efficiency, safety and effectiveness [54].

Mentally archived patterns, or prototypes, used in the assessment of blood loss

Typical prototype – normal blood loss

Considering assessment of blood loss in context with this evidence [52,53], a 'typical' woman will have a normal amount of blood loss and be well, post-delivery. Most health professionals will have witnessed this outcome and will therefore have a clearly stored mental pattern of this 'typical (normal blood loss) prototype' [52]. They will use this for unconsciously comparing subsequent blood losses to estimate the probability of various outcomes and for determining appropriate courses of action.

Typical PPH prototype – rapid, visible blood loss

Health professionals are also likely to have a 'typical PPH prototype' stored in their memory. As simulated PPH training commonly focuses on rapid, noticeable blood loss, this may be considered as a 'typical PPH', with most health professionals able to recognise this type of excessive blood loss.

Missed/delayed diagnosis of PPH – mismatched to typical (normal blood loss) prototype

One of the difficulties in recognising women with compensated, insidious or hidden blood loss (internal bleeding or blood loss retained within the uterus and/or vagina) is that these women may appear to match the typical, normal blood loss prototype. They will often appear well (due to the compensatory mechanisms) and will appear to have a normal blood loss (if bleeding is insidious or hidden). In the absence of diagnostic tools, and where the subtle cues associated with deployment of the compensatory mechanisms go unrecognised, blood loss will be regarded as 'typical' and may therefore be overlooked. Until there is a 'mismatch' or 'surprise stimulus' [52], such as 'faint~~ness~~ing' or 'loss of ~~un~~consciousness' [55], there will be no new situational awareness to alert health professionals to reassess the situation.

A lack of training on this type of blood loss means that the only way to assimilate the mental patterns necessary for automatic recognition will be through experience and feedback. Recognition will only occur when the present situation can be matched to previously archived patterns. This is because "we only perceive what we know ... in a re-cognition, or renewed cognition of an existing pattern" [56](p2). To facilitate pattern assimilation of this presentation of blood loss, the environment must provide regular and valid cues, and health professionals must have feedback to learn the relevance of them [44,52,53]. In the case of rapid PPH, the fact that it is often obvious and requires immediate management, means that feedback on this type of blood loss is immediately available. However, feedback on cases of compensated, insidious or hidden blood loss are often ambiguous (the women appears well) or does not occur (because symptoms manifest after transfer to the postnatal ward or home). This means that opportunities for staff to reflect on cues that may have been present at the time of the original blood loss assessment will be missed. Another factor that affects the retrievability of patterns relates to the salience of an event. For example, witnessing the collapse of a woman following insidious and protracted blood loss, will give prominence to this example in the minds of the health professionals who witnessed it and may mean that it is perceived as a rare and catastrophic event. Giving salience to less frequently experienced presentations of blood loss, through training, education and feedback, may help to add prominence to such events and make them accessible during decision-making. Inexperienced staff will need to 'construct instances' according to rules learnt through training and education. In these circumstances, 'imaginability' will be important to their ability to evaluate the probability of certain blood loss outcomes [45]. Imaginative training and education using real-life clinical vignettes alongside simulated scenarios may be one way of achieving this.

Decision-making in other areas of practice

Many of the solutions introduced to address delays in diagnosis of PPH appear to have favoured normative models and System 2 decision-making. Some of the difficulties associated with designing, implementing and evaluating tools that support decision-making in practice were highlighted in a cluster randomised trial in the UK [57], in which a decision tool to support diagnosis of active labour was implemented in maternity units. The decision tool comprised a paper-based algorithm, which required midwives to collect various items of information which were then used in a structured way to inform their judgement about the diagnosis. The results were described as 'both complex and difficult to interpret' with the tool affecting individuals, and their work processes, in unpredictable ways. The study authors suggested that further research was warranted to explore midwifery decision-making, based on an observation that decision-making often relied on intuition, or heuristics. Other studies have reiterated and supported these findings. A study exploring recognition of dying [41] found that decision-making was 'time-dependent, on-going and iterative and relied heavily on intuition' (p1). Similarly, in two studies exploring how vital signs were used in practice to detect deterioration in hospitalised patients, the main process described by nurses was 'intuitive knowing', with vital signs being used to validate rather than inform intuitive feelings [58,59]. Such findings should be carefully considered when developing, introducing and evaluating tools to support clinical decision-making in practice. Initiatives to support PPH diagnosis should also draw on psychological theories of decision-making and human factors science to align strategies with decision-making methods commonly used in practice.

Summary

Maternal mortality and morbidity from PPH is a persistent and growing problem, with delays in recognising and responding to blood loss being important factors in poor outcomes. Training to address the delays in diagnosis has traditionally focussed on volume estimation of blood loss with solutions, such as early warning scores and quantification methods, based on normative models. Dual process theory suggests that current solutions may either may be focusing on the wrong problem, or are at odds with how decision-making in the real-world of clinical practice actually occurs. Health professionals appear to use mainly ~~System 1~~intuitive, automatic processing, to assess blood loss, with ~~System 2,~~ methodical, deliberate, analytical reasoning, often used once a PPH diagnosis has been made. As the prominent method of decision-making may rely~~relies~~ on a mental database of blood loss patterns, staff should be supported to expand their mental database to reduce the use of error-prone heuristics. However, any solutions should be evidence-based and developed in conjunction with psychologists; replicating methods used by NDM researchers who have informed and developed the field of human factors. The findings of this review should be considered alongside current efforts to address the issues associated with blood loss assessment to address the ever increasing tide of delayed and missed diagnosis of PPH.

Practice points

- Training, focusing on the physiology and mechanisms of the compensatory phase of hypovolaemic shock, would promote understanding of the effects that any amount of blood loss can have on individual women.
- Experienced staff should make explicit the cues used during assessment and evaluation of blood loss to help less experienced staff build their database of patterns to improve their decision-making.
- Promoting the benefits of ~~system 2,~~ analytical decision-making to inexperienced staff, may help in the detection of some cases of PPH that are currently missed or delayed.

Research agenda

- Cognitive task analysis methods should be used to identify the cues and decision-making methods used by experts.
- The design of technologies, processes and work systems to support PPH diagnosis should be made in conjunction with ‘human factors’ experts.
- Providing feedback to staff on cases of delayed diagnosis of PPH is essential to facilitating pattern assimilation, necessary to reduce mismatching of these cases to a normal blood loss pattern.
- Definitions of PPH should be developed that are useful for treatment, audit and research, which include measures of morbidity that are important to women.

Conflict of interest

The authors have no conflicts of interest.

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References

[1] L. Say, D. Chou, A. Gemmill, O. Tuncalp, A.B. Moller, J. Daniels, et al., Global causes of maternal death: a WHO systematic analysis, *Lancet Global Health* **2** (6), 2014, e323–e333 https://doi.org/10.1016/S2214-109X(14)70227-X.

[2] M. Knight, W. Callaghan, C. Berg, S. Alexander, M.H. Bouvier-Colle, J. Ford, et al., Trends in postpartum hemorrhage in high resource countries: a review and recommendations from the International Postpartum Hemorrhage Collaborative Group, *BMC Pregnancy Childbirth* **9** (55), 2009 https://doi.org/10.1186/1471-2393-9-55.

[3] M.B.K. Knight, D. Tuffnell, H. Jayakody, J. Shakespeare, R. Kotnis, S. Kenyon, et al., Saving lives, improving mothers' care - lessons learned to inform maternity care from the UK and Ireland confidential Enquiries into maternal deaths and morbidity 2014-16, 2018, National Perinatal Epidemiology Unit, University of Oxford; Oxford.

[4] J.M. Mhyre, R. D'Oria, A.B. Hameed, J.R. Lappen, S.L. Holley, S.K. Hunter, et al., The maternal early warning criteria: a proposal from the national partnership for maternal safety, *J Obstet Gynecol Neonatal Nurs* **43** (6), 2014, 771–779 https://doi.org/10.1111/1552-6909.12504.

[5] R.C. Pacagnella, J.P. Souza, J. Durocher, P. Perel and J. Blum, A systematic review of the relationship between blood loss and clinical signs, *PLoS One* **8** (3), 2013, e57594 https://doi.org/10.1371/journal.pone.0057594.

[6] C. Larsson, S. Saltvedt, I. Wiklund, S. Pahlen and E. Andolf, Estimation of blood loss after cesarean section and vaginal delivery has low validity with a tendency to exaggeration, *Acta Obstet Gynecol Scand* **85** (12), 2006, 1448–1452 https://doi.org/10.1080/00016340600985032.

[7] A. Hancock, A.D. Weeks and D.T. Lavender, Is accurate and reliable blood loss estimation the 'crucial step' in early detection of postpartum haemorrhage: an integrative review of the literature, *BMC Pregnancy Childbirth* **15** (1), 2015, 230 https://doi.org/10.1186/s12884-015-0653-6.

[8] J. Bonnar, Massive obstetric haemorrhage, *Best Pract Res Clin Obstet Gynaecol* **14** (1), 2000, 1–18 https://doi.org/10.1053/beog.1999.0060.

[9] J.A. Pritchard, Changes in the blood volume during pregnancy and delivery, *Anesthesiology* **26** (4), 1965, 393–399.

[10] T.A. Johnston and K. Grady, On behalf of the guidelines committee of the ~~r~~Royal College of ~~o~~Obstetricians and Gynaecologists (RCOG) ~~m~~Maternal collapse in pregnancy and the puerperium. Green-top guideline No. 56, 2011, RCOG; London.

[11] D. Stables and J. Rankin, Physiology in childbearing, second ed., 2005, Elsevier; London.

[12] World Health Orgnaization (WHO), Recommendations on prevention and treatment of postpartum haemorrhage, 2012, WHO; Geneva.

[13] E. Mavrides, S. Allard, E. Chandraharan, P. Collins, L. Green, B.J. Hunt, et al., On behalf of the guidelines committee of the ~~r~~Royal College of ~~o~~Obstetricians and Gynaecologists (RCOG), ~~p~~Prevention and management of postpartum haemorrhage. Greentop guideline No. 52, *BJOG* **124**, 2016, e106–e149.

[14] M. Knight, M. Nair, D. Tuffnell, S. Kenyon, J. Shakespeare, P. Brocklehurst, et al., On behalf of MBRRACE-UK, Saving lives, improving mothers' care - surveillance of maternal deaths in the UK 2012-14 and lessons learned to inform maternity care from the UK and Ireland confidential Enquiries into maternal deaths and morbidity 2009-14, 2016, University of Oxford; Oxford.

[15] J. Bamber, G. Butcher, S. Kenyon, M. Knight, J. Kurinczuk, A. Lobo, et al., Prevention and treatment of haemorrhage, In: M. Knight, S. Kenyon, P. Brocklehurst, J. Neilson, J. Shakespeare and J.J. Kurinczuk, (Eds.), *Saving lives, improving mothers' care - lessons learned to inform future maternity care from the UK and Ireland confidential Enquiries into maternal deaths and morbidity 2009–12,* 2014, National Perinatal Epidemiology Unit, University of Oxford; Oxford, 120.

[16] R. Kerr and A.D. Weeks, Postpartum haemorrhage: a single definition is no longer enough, *BJOG – An Int J Obstet Gynaecol* **124** (5), 2017, 723–726.

[17] C.F. Wilcox, A.B. Hunt and C.A. Owen, The measurement of blood lost during cesarean section, *Obstet Gynecol Surv* **14** (4), 1959, 534–535.

[18] M. Newton, L.M. Mosey, G.E. Egli, W.B. Gifford and C.T. Hull, Blood loss during and immediately after delivery, *Obstet Gynecol* **17** (1), 1961, 9–17.

[19] M. Newton and C.J. Blackburn, Blood loss following cesarean section determined by the acid hematin photometric method, *Am J Obstet Gynecol* **84** (2), 1962, 257–260 https://doi.org/10.1016/0002-9378(62)90438-6.

[20] H.A. Brant, Blood loss at caesarean section, *BJOG – An Int J Obstet Gynaecol* **73** (3), 1966, 456–459 https://doi.org/10.1111/j.1471-0528.1966.tb05188.x.

[21] H.A. Brant, Precise estimation of postpartum haemorrhage: difficulties and importance, *BMJ* **1** (5537), 1967, 398–400 https://doi.org/10.2307/25411170.

[22] V. Diaz, E. Abalos and G. Carroli, Methods for blood loss estimation after vaginal birth, *Cochrane Database Syst Rev* **2**, 2018.

[23] W.H. Zhang, C. Deneux-Tharaux, P. Brocklehurst, E. Juszczak, M. Joslin and S. Alexander, Effect of a collector bag for measurement of postpartum blood loss after vaginal delivery: cluster randomised trial in 13 European countries, *BMJ* **340**, 2010, c293 https://doi.org/10.1136/bmj.c293.

[24] G. Lewis, The confidential enquiry into maternal and child health (CEMACH). Saving Mothers' lives: reviewing maternal deaths to make motherhood safer - 2003-2005. The Seventh Report on Confidential Enquiries into Maternal Deaths in the United Kingdom, 2007, CEMACH; London.

[25] D.E. Bick, J. Sandall, M. Furuta, M.Y. Wee, R. Isaacs and G.B. Smith, A national cross sectional survey of heads of midwifery services of uptake, benefits and barriers to use of obstetric early warning systems (EWS) by midwives, *Midwifery* **30** (11), 2014, 1140–1146 https://doi.org/10.1016/j.midw.2014.03.016.

[26] A.P. McGlennan and K. Sherratt, Charting change on the labour ward, *Anaesthesia* **68** (4), 2013, 338–342 https://doi.org/10.1111/anae.12189.

[27] M. Jones, NEWSDIG: the national early warning score development and implementation group, *Clin Med* **12** (6), 2012, 501–503 https://doi.org/10.7861/clinmedicine.12-6-501.

[28] S. Singh, A. McGlennan, A. England and R. Simons, A validation study of the CEMACH recommended modified early obstetric warning system (MEOWS), *Anaesthesia* **67** (1), 2012, 12–18 https://doi.org/10.1111/j.1365 2044.2011.06896.x.

[29] C. Carle, P. Alexander, M. Columb and J. Johal, Design and internal validation of an obstetric early warning score: secondary analysis of the intensive care national audit and research centre case mix programme database, *Anaesthesia* **68** (4), 2013, 354–367 https://doi.org/10.1111/anae.12180.

[30] N. Mackintosh, K. Watson, S. Rance and J. Sandall, Value of a modified early obstetric warning system (MEOWS) in managing maternal complications in the peripartum period: an ethnographic study, *BMJ Qual Saf* **23** (1), 2014, 26–34 https://doi.org/10.1136/bmjqs-2012-001781.

[31] G.J. Tortora and B.H. Derrickson, Principles of anatomy and physiology, 2013, John Wiley & Sons; London.

[32] N. Vousden, E. Lawley, S. Goudar, M. Gidiri, P.T. Seed, J. Sandall, et al., Cradle-3: a trial of a novel device to reduce maternal mortality/morbidity in low resource settings, In: R.M. Adanu, (Ed), *The XXII FIGO world congress of gynecology & obstetrics; 14-19 october, 2018,* **vol. 143**, 2018, International Journal of Gynecology & Obstetrics; Rio de Janeiro, Brazil, 233, S3.

[33] H.L. Nathan, A. El-Ayadi, N.L. Hezelgrave, P. Seed, E. Butrick, S. Miller, et al., Shock index: an effective predictor of outcome in postpartum haemorrhage?, *BJOG An Int J Obstet Gynaecol* **122** (2), 2014, 268–275 https://doi.org/10.1111/1471-0528.13206.

[34] A. Klein, P. Arnold, R. Bingham, K. Brohi, R. Clark, R. Collis, et al., AAGBI guidelines: the use of blood components and their alternatives 2016, *Anaesthesia* **71** (7), 2016, 829–842.

[35] L. Sibley, L. Caleb-Varkey, J. Upadhyay, R. Prasad, E. Saroha, N. Bhatla, et al., Recognition of and response to postpartum hemorrhage in rural northern India, *J Midwifery Women's Health* **50** (4), 2005, 301–308 https://doi.org/10.1016/j.jmwh.2005.03.006.

[36] A. Matsuyama and K. Moji, Perception of bleeding as a danger sign during pregnancy, delivery, and the postpartum period in rural Nepal, *Qual Health Res* **18** (2), 2008, 196–208 https://doi.org/10.1177/1049732307312390.

[37] N. Kalim, I. Anwar, J. Khan, L.S. Blum, A.C. Moran, R. Botlero, et al., Postpartum haemorrhage and eclampsia: differences in knowledge and care-seeking behaviour in two districts of Bangladesh, *J Health Popul Nutr* **27** (2), 2009, 156–169.

[38] S. Ononge, E.S. Okello and F. Mirembe, Excessive bleeding is a normal cleansing process: a qualitative study of postpartum haemorrhage among rural Uganda women, *BMC Pregnancy Childbirth* **16** (1), 2016, 211 https://doi.org/10.1186/s12884-016-1014-9.

[39] A. Hancock, How much is too much? Exploring clinical recognition of excessive maternal blood loss during childbirth (PhD Thesis), 2017, University of Manchester; United Kingdom.

[40] J. Baron, The point of normative models in judgment and decision making, *Front Psychol* **3** (577), 2012, 1–3 https://doi.org/10.3389/fpsyg.2012.00577.

[41] P. Taylor, D. Dowding and M. Johnson, Clinical decision making in the recognition of dying: a qualitative interview study, *BMC Palliat Care* **16** (1), 2017, 1–11 https://doi.org/10.1186/s12904-016-0179-3.

[42] K.E. Stanovich and R.F. West, Individual differences in reasoning:implications for the rationality debate?, *Behav Brain Sci* **23**, 2000, 645–726.

[43] D. Kahneman, Thinking, fast and slow, 2011, Macmillan; London.

[44] D. Kahneman and G. Klein, Conditions for intuitive expertise: a failure to disagree, *Am Psychol* **64** (6), 2009, 515–526 https://doi.org/10.1037/a0016755.

[45] A. Tversky and D. Kahneman, Judgment under uncertainty: heuristics and biases, 1973, Springer; Berlin.

[46] J. Cioffi and R. Markham, Clinical decision-making by midwives: managing case complexity, *J Adv Nurs* **25** (2), 1997, 265–272 https://doi.org/10.1046/j.1365-2648.1997.1997025265.x.

[47] S.E. Dreyfus and H.L. Dreyfus, A five-stage model of the mental activities involved in directed skill acquisition, 1980 https://apps.dtic.mil/dtic/tr/fulltext/u2/a084551.pdf, Accessed 13 March 2017.

[48] P. Benner, From novice to expert, *Am J Nurs* **82** (3), 1982, 402–407.

[49] O. Amidzic, H.J. Riehle, T. Fehr, C. Wienbruch and T. Elbert, Pattern of focal [gamma]-bursts in chess players, *Nature* **412** (6847), 2001, 603 https://doi.org/10.1038/35088119.

[50] H.A. Simon, What is an "explanation" of behavior?, *Psychol Sci* **3** (3), 1992, 150–161.

[51] J.C. Flanagan, The critical incident technique, *Psychol Bull* **51** (4), 1954, 327–358.

[52] Rapid decision making on the fire ground, G.A. Klein, R. Calderwood and A. Clinton-Cirocco, (Eds.), *Proc Hum Factors Ergon Soc Annu Meet* **30**, 1986, 576–580.

[53] G. Klein, Naturalistic decision making, *Hum Factors- J Human Factors Ergon Soc* **50** (3), 2008, 456–460.

[54] A.L. Russ, R.J. Fairbanks, B.T. Karsh, L.G. Militello, J.J. Saleem and R.L. Wears, The science of human factors: separating fact from fiction, *BMJ Qual Saf* **22** (10), 2013, 802–808 https://doi.org/10.1136/bmjqs-2012-001450.

[55] A. Vaate bij de, R. Coleman, H. Manneh and G. Walraven, Knowledge, attitudes and practices of trained traditional birth attendants in the Gambia in the prevention, recognition and management of postpartum haemorrhage, *Midwifery* **18** (1), 2002, 3–11 https://doi.org/10.1054/midw.2001.0289.

[56] J. Daalmans, Topic letter 13: changing mind-sets, changing results. A neuropsychological perspective, 2016 http://www.daalmans.nl/en/literature/13_changingmindsetschangingresults.html, Accessed 7 December 2016.

[57] D.W. Dowding, H.L. Cheyne and V. Hundley, Complex interventions in midwifery care: reflections on the design and evaluation of an algorithm for the diagnosis of labour, *Midwifery* **27** (5), 2011, 654–659.

[58] M. Odell, C. Victor and D. Oliver, Nurses' role in detecting deterioration in ward patients: systematic literature review, *J Adv Nurs* **18** (1), 2009, 3–11 https://doi.org/10.1054/midw.2001.0289.

[59] M. Odell, Detection and management of the deteriorating ward patient: an evaluation of nursing practice, *J Clin Nurs* **24** (1–2), 2015, 173–182 https://doi.org/10.1111/jocn.12655.

[60] P. Mitchell, Safer Care Human Factors for Healthcare: Course Handbook, 2013, The Health Foundation; London.

Highlights

- Evidence to recommend specific blood loss assessment methods for practice is lacking.
- PPH recognition is assumed to be a linear process, with volume as the lead component.
- Studies suggest that automatic, intuitive decision-making is the primary method for assessing blood loss and that skilled, intuitive decision-making develops from knowledge, experience and feedback.
- Solutions should be designed along with psychologists and human factor experts.

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