Peake expiratory flow (PEF) monitoring is recommended in asthma guidelines as a tool for assessing severity, monitoring response to treatment, detecting exacerbations, identifying triggers, and providing objective justification for treatment to the patient. However, some clinicians have expressed concerns about its relevance in the management of asthma. We have identified a sevenfold variation in the scale of existing PEF charts, with resulting wide variation in the appearance of the same PEF data on different charts. There is an obvious need for standardisation of PEF charts to avoid confusion for patients and to allow development of pattern recognition skills by clinicians. Evidence is provided from visual perception studies to suggest that preference should be given to a horizontally compressed PEF chart to facilitate identification of exacerbations and of overall trends, but this needs to be formally evaluated by retrospective and prospective studies. It is hoped that clinical expertise in PEF pattern recognition can eventually be incorporated into electronic decision making algorithms, as has occurred in occupational asthma, but, in the meantime, the ideal PEF chart for asthma management will represent a compromise between ease of manual data entry and ease of interpretation.

Peak expiratory flow (PEF) monitoring is recommended in asthma guidelines as a tool for assessing severity, monitoring response to treatment, detecting exacerbations, identifying triggers, and providing objective justification for treatment to the patient. The incorporation of PEF based action plans into coordinated self-management education programmes has been shown to improve health outcomes. However, despite these recommendations, there are few practical resources available for interpretation of PEF data in clinical practice.

EXISTING TOOLS FOR INTERPRETATION OF PEAK FLOW DATA
In a routine consultation a clinician will not usually have access to computerised processing of PEF data, so the conventional PEF outcomes used in clinical trials to assess change in status (such as mean morning PEF or diurnal variability) are not practicable. For PEF based action plans the clinician nominates a threshold PEF value which represents a significant change from the patient’s usual status, at which the patient is advised to change his/her treatment. Guideline recommendations for calculation of these action points are, for simplicity, based on percentage calculations from predicted or personal best PEF. The sensitivity and specificity of such percentage criteria in identifying exacerbations is poor compared with that of standard deviation criteria, as the latter take into account the patient’s previous level of PEF variability. However, standard deviation calculations require computerised entry and analysis. Boggs and colleagues have used statistical process control charts for display of PEF data but, once again, this process requires computerised processing.

The visual recognition of patterns of airflow obstruction was described by Turner-Warwick in 1977, shortly after the introduction of portable PEF meters. Mitchell and colleagues later validated inspection of PEF charts for the identification of treatment response in chronic airflow limitation. The most striking example of the use of visual inspection of PEF charts has been in the field of occupational asthma. In a series of seminal articles published in Thorax, the use of PEF monitoring in the diagnosis of occupational asthma was described in 1979 by Burge and colleagues, with subsequent validation of expert visual interpretation of PEF charts against specific challenges and eventual incorporation of these processes into a computerised diagnostic algorithm (OASYS). 

HUMAN VISUAL PERCEPTION AND PATTERN RECOGNITION SKILLS
The use of a chart or graph is regarded as the most efficient way to detect outlying or abnormal values in a series dataset. Visual assessment of PEF charts might appear to be very “soft” science. However, in visual perception literature it is axiomatic that human visual pattern recognition processes are highly sophisticated and reliable. In a recent review, Grill-Spector stated that “One of the greatest mysteries in cognitive science is the human ability to recognize visually-presented objects with high accuracy and lightning speed. Interest in how human object recognition works is heightened by the fact that efforts to duplicate this ability in machines have not met with extraordinary success”. This perspective is highlighted by the retention of visual displays in environments (both medical and non-medical) which require rapid decisions. For example, intensive care units still display electrocardiogram traces for instantaneous diagnosis of arrhythmias such as ventricular tachycardia, despite the availability of complex computerised analysis. It has long been accepted that the format of a visual display affects the way in which graphed data are interpreted. For example, the usefulness of electrocardiogram traces is completely dependent on universal standardisation of the...
recording scale; and we would quickly abandon analogue clocks if the “12” was orientated randomly around the dial. In the field of occupational asthma, standardisation of PEF charts was implemented at an early stage in recognition of its importance in the facilitation of expert pattern recognition.

**HOW MUCH VARIATION EXISTS BETWEEN PEF CHARTS AT PRESENT?**

Asthma guidelines, while recommending PEF monitoring, do not specify a particular format for recording PEF. We have been able to obtain 17 different full range (>500 l/min) PEF charts (table 1): eight packaged with PEF meters, four distributed by pharmaceutical companies, two published as online supplements to asthma guidelines (Global Initiative for Asthma (GINA) website; British asthma guideline (BTS/SIGN) website) which reproduces the Asthma UK brochure “Your Personal Asthma Diary and Action Plan”(9), a 1 year booklet (FP1010) available from the UK National Health Service, a prototype chart from our asthma clinic, and an OASYS chart designed for computerised plotting.

There was considerable variation between the charts (table 1) in the range of PEF values which could be plotted, the number of measurements per day, and the number of days’ data per page, the latter ranging from 4 days (GINA) to 57 days (Asthma Daily Record Card). Because of these variations, differences in the scale of the charts were not immediately obvious. Chart scale, calculated as the ratio of standardised vertical height to horizontal width, ranged from 100:825 for the GINA chart to 100:119 for the Asthma UK chart. This represents an almost sevenfold difference in scale between the two guideline charts. The scale rose to 100:82 on the prototype chart and 100:39 on the occupational asthma chart.

**EFFECT OF VARIATION IN CHART FORMAT ON THE INTERPRETATION OF PEF DATA**

The effect of chart scale on the appearance of PEF data can be seen by plotting a sample exacerbation on each chart. Figure 1 shows a severe exacerbation experienced by a 49 year old woman during a viral respiratory infection on a background of good asthma control, with PEF recorded from twice daily electronic spirometry on a MicroMedical DiaryCard spirometer. Peak flow fell by 31% (156 l/min, 8.3 standard deviations) below baseline over 4 days, then recovered over a further 6 days. For each chart the angle of onset of the exacerbation (mean slope over days 1–4) was reported as degrees from the horizontal. This angle ranged from 10° (GINA) to 52° (Asthma UK), increasing to 62° on the prototype chart and 75° on the occupational asthma chart (table 1). The resulting variation in the qualitative appearance of the sample exacerbation was striking. On horizontally expanded charts (fig 1A and B) the exacerbation onset and resolution were difficult to identify, but on horizontally compressed charts (fig 1C and D) the exacerbation stood out abruptly from adjacent data.

The implications of this variation in scale are obvious. Clinicians who repeatedly view PEF charts at patient visits should be able to develop clinical pattern recognition skills in the interpretation of PEF data. However, if similar episodes may have a markedly different appearance according to which PEF chart was used, there is no opportunity for these skills to develop. In addition, if a whole exacerbation episode (steady state-deterioration-recovery-steady state) cannot be readily identified retrospectively on a particular chart format, then prospective detection of an evolving exacerbation on the same chart would be extremely difficult. It is relevant to note that highly compressed displays were used to demonstrate the temporal associations between viral infections and asthma exacerbations, and to identify the differences between the V-shaped PEF changes of viral exacerbations and the chaotic PEF variation of uncontrolled asthma. A highly compressed chart appears to have been used in validating visual inspection of treatment response in COPD.

The number of weeks of data which can be recorded on each chart page is also likely to have an impact on the interpretation of PEF data. The scale calculations in table 1 assumed a continuous record of 31 days but, in practice, charts displaying only a few days per page (e.g. GINA, AsthmaCare, UK Government booklet) would be difficult to interpret because of breaks in continuity between pages. Given the known time course of the response to inhaled corticosteroids and of exacerbations, long term PEF data,

<table>
<thead>
<tr>
<th>Chart Source</th>
<th>No of days of data per page</th>
<th>Range of PEF values (min-max, l/min)</th>
<th>Scale</th>
<th>Angle of onset of exacerbation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Initiative for Asthma Guidelines website</td>
<td>4</td>
<td>60–800</td>
<td>100:825</td>
<td>10°</td>
</tr>
<tr>
<td>Allersearch Packaged with PEF meter</td>
<td>23</td>
<td>50–700</td>
<td>100:282</td>
<td>22°</td>
</tr>
<tr>
<td>AsthmaCare Pharmaceutical company</td>
<td>14</td>
<td>0–1000</td>
<td>100:345</td>
<td>24°</td>
</tr>
<tr>
<td>MicroPeak Packaged with PEF meter</td>
<td>28</td>
<td>100–800</td>
<td>100:334</td>
<td>24°</td>
</tr>
<tr>
<td>FDE Packaged with PEF meter</td>
<td>14</td>
<td>0–700</td>
<td>100:324</td>
<td>25°</td>
</tr>
<tr>
<td>Breath Alert Packaged with PEF meter</td>
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<td>100–700</td>
<td>100:268</td>
<td>29°</td>
</tr>
<tr>
<td>Assess Packaged with PEF meter</td>
<td>14</td>
<td>50–900</td>
<td>100:251</td>
<td>31°</td>
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<tr>
<td>Asthma Daily Record Card Pharmaceutical company</td>
<td>57</td>
<td>0–1000</td>
<td>100:246</td>
<td>32°</td>
</tr>
<tr>
<td>Personal best Packaged with PEF meter</td>
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<td>50–900</td>
<td>100:237</td>
<td>33°</td>
</tr>
<tr>
<td>Allen &amp; Hanburys Pharmaceutical company</td>
<td>42</td>
<td>50–650</td>
<td>100:222</td>
<td>33°</td>
</tr>
<tr>
<td>MiniWright Packaged with PEF meter</td>
<td>42</td>
<td>0–700</td>
<td>100:230</td>
<td>33°</td>
</tr>
<tr>
<td>Peak flow meter charts (FP1010) UK NHS</td>
<td>14</td>
<td>0–700</td>
<td>100:221</td>
<td>34°</td>
</tr>
<tr>
<td>Big Bright Blue Breathing Book Pharmaceutical company</td>
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<td>0–650</td>
<td>100:174</td>
<td>41°</td>
</tr>
<tr>
<td>Airzone Packaged with PEF meter</td>
<td>32</td>
<td>100–700</td>
<td>100:157</td>
<td>44°</td>
</tr>
<tr>
<td>Your Personal Asthma Diary and Action Plan Asthma UK, reproduced on OASYS chart</td>
<td>28</td>
<td>100–700</td>
<td>100:119</td>
<td>52°</td>
</tr>
<tr>
<td>Prototype chart Woolcock Institute of Medical Research</td>
<td>56</td>
<td>0–750</td>
<td>100:82</td>
<td>62°</td>
</tr>
<tr>
<td>Occupational asthma format Bright and Burge</td>
<td>N/A</td>
<td>N/A</td>
<td>100:39</td>
<td>76°</td>
</tr>
</tbody>
</table>

*Scale was calculated as the ratio of vertical height to horizontal width. The vertical height was standardised such that 100 mm represented a range of 0–800 l/min, then the horizontal width was calculated for a period of 31 days.
†Angle formed by the first 4 days of the sample exacerbation in degrees from the horizontal.
‡Axis unlabelled but 10 major divisions on vertical axis, so analysed as 0–1000 l/min for full range chart.
§This booklet contains sufficient 2 week charts for 1 year of monitoring.
∥This chart format is designed for computerised entry of multiple daily PEF values. A limited PEF range relevant to the individual patient is displayed, with 20 min = 10 mm and 1 day = 5 mm.
which may be used in patients with severe asthma or poor perception, would be best displayed with at least 4 weeks per page in order to identify time trends without excessive visual interruption.

**NEURAL BASIS FOR THE EFFECT OF CHART SCALE ON APPEARANCE OF EXACERBATIONS**

The qualitative differences in the appearance of PEF data on different charts are consistent with existing knowledge about visual search processes from psychometric and functional neuroimaging studies. Attentive visual search involves serial focus on individual data points, but it has consistently been found that visual working memory can handle only 3–4 such individual points at once. A second type of visual search process involves the pre-attentive identification of salient objects. These may be actual objects or perceived objects created by visual binding of multiple putatively separable data points. We use this process when we visually integrate the dots of a Neo-Impressionist painting. Pre-attentive object detection is enhanced if the object “pops out” from the background data as an emergent feature, with “pop out” enhanced by orientation (angle) contrast. Recent functional neuroimaging studies have localised serial focusing to the primary visual cortex and object perception to the lateral occipital complex, and have shown that visual grouping “frees up” the primary visual cortex for attention to new items.

These concepts can be applied to the observed differences between PEF charts. On horizontally expanded charts (fig 1A and B) each PEF is viewed as a separate point and is therefore compared in working visual memory with only a few adjacent values. Visual attention on an expanded chart thus focuses on day to day variation rather than on overall trends. Thus, importantly, visual recognition of onset of an exacerbation on a compressed chart appears to take into account the patient’s existing level of variability.

**POTENTIAL IMPLICATIONS FOR CONSTRUCTION OF ASTHMA ACTION PLANS**

In view of the poor performance of percentage based action points in the diagnosis of asthma exacerbations, as shown in fig 2, it is interesting to speculate about the potential for visual estimation of quality control based action points from a compressed PEF chart. As a rough guide, the “band” of baseline PEF variability and its slope indicating whether PEF is stable or is rising or falling (as illustrated in Mitchell et al). The exacerbation then “pops out” from the background data as a V-shaped object.

Furthermore, if fig 1C and D are uncovered from left to right as if the PEF data are being viewed prospectively, new PEF data which are similar to previous values appear to be visually added to the existing “band”. However, the first low PEF (in this case, four standard deviations below mean) is too far away to be visually bound and is, instead, perceived as a separate, clearly abnormal point. This effect is enhanced by viewing the chart from a distance, suggesting that detection of the exacerbation is not due to examination of fine detail. Thus, importantly, visual recognition of onset of an exacerbation on a compressed chart appears to take into account the patient’s existing level of variability.

**LIMITATIONS OF MANUAL DATA ENTRY ON COMPRESSED PEF CHARTS**

Electronically entered data can be displayed in any desired format (as with OASYS), but the extent to which the scale of
paper PEF charts can be horizontally compressed is usually limited by the need for manual data entry, with an attendant burden to patients. Lack of standardisation of PEF charts hence reduce the burden of monitoring for patients. Additional features (such as major/minor gridlines, repeated axis labels) can markedly improve ease of data entry and hence reduce the burden of monitoring for patients.

CONCLUSIONS
Asthma guidelines highlight the usefulness of PEF monitoring for assessment of asthma severity, monitoring of response to treatment, and detection of exacerbations. However, some clinicians have expressed concerns about the relevance of PEF monitoring, particularly because of poor adherence to treatment. Lack of standardisation of PEF charts may have contributed to these problems, as indifference or confusion by clinicians in the interpretation of PEF data is readily sensed by patients and is reflected in poor adherence, which further reduces the enthusiasm of the clinician. At the very least, there is an obvious need for standardisation of PEF charts to avoid confusion for patients and to allow development of pattern recognition skills by clinicians. Our observations suggest that preference should be given to a horizontally compressed chart to facilitate identification of exacerbations and of overall trends, but this hypothesis must be evaluated by retrospective and prospective studies. Ultimately, clinical expertise in PEF pattern recognition may be able to be incorporated into electronic decision making algorithms, as has occurred in occupational asthma.

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REFERENCES