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Dynamics of Spatial Attention and its relation with Working Memory Load

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Locating and attending to stimuli in the nearby environment plays an important role in human performance. Applied cognitive psychology research suggests that the amount of information and complexity of operations on subsets of information, increased working memory load experienced by performer, is an important variable that significantly affects human spatial attention performance. Recent advances in research have explored the effect of working memory load on different aspects of spatial attention, viz., orienting attention, inhibition of return, pseudoneglect, and retro cueing. Research attempts that have employed multiple paradigms produced mixed and weak generalizations regarding the relationship between working memory load and the dynamic nature of spatial attentional sub-phenomena. And, a few aspects of these spatial attentional sub-phenomena are not explored yet which are necessary for prediction of a comprehensive or molecular spatial attention behaviour. This suggests replications of existing findings along with modification of paradigms and testing of those on different ecological settings. Potential implications of observed findings in intervention or training plan designing and future testing avenues for existing tools/techniques (e.g., Kindergarten and Computerised Progressive Attentional Training) available in applied cognitive psychology disciplines for promoting health, education

and human performance with machines has also been discussed in this article.

Keywords: Spatial Attention, Working Memory Load, Inhibition of Return, Pseudoneglect and Retro Cueing

The study of spatial attention has been a popular phenomenon in recent decades of attention research. The journey of exploration of spatial attention, elucidates a few phenomena, namely, spatial Attention, Inhibition of Return, Retro Cueing, and Pseudoneglect. This journey fruited the innovation of a few paradigms such as the exogenous/endogenous/retro cueing paradigm, the landmark task paradigm, the line bisection paradigm, etc., and, these were pioneered to strengthen the emerging generalizations regarding orienting attention (Posner, 1980; Posner, & Petersen, 1990; Griffin & Nobre, 2003;). Uncovering multiple underpinnings of spatial attention has strengthened our understanding of it in scenarios such as education, training, and clinical rehabilitation.

Recent research in cognitive psychology, specifically in the labs of applied cognitive psychology such as human factors and neuro-ergonomics have suggested a few important variables contingent to human behavior which might significantly affect our attention performance or interact with it are load, arousal, attention set, anxiety, etc. (Eysenck et al., 2007; Luck et al., 2021; Maness et al., 2022). Load induced by the task or surrounding environment to a performer during task performance has been identified as a potential variable, which can crucially affect human performance, by affecting learning, endurance, and safety of the individual (Wickens et al., 2022; Regan, & Oviedo-Trespalacios, 2022; Longo, & Leva, (Eds.). 2019; 2017; Jansen et al., 2017). Along with applied discipline, fundamental research has also researched well about workload and its interaction with attentional performance (Christophel et al., 2017; Draheim et al., 2022; Oberauer, 2019; Wickens, 2002; van Ede, & Nobre, 2023). However, initially, these researches mainly discussed load's interaction with sustained attention or vigilance (Parasuraman, 1979; Caggiano & Parasuraman, 2004; See et al., 1995). And, multiple studies have suggested that orienting attention and sustained attention are two interrelated phenomena (Singh & Sabat, 2004; Singh et al., 2006; Singh & Singh, 2014; Yadav et al., 2020). Thus, researchers tested the interaction of load with different aspects of selective attention, which resulted in large literature discussing distractor processing, orienting, engagement and disengagement biases, and attentional control in different shades of load (Brockhoff et al., 2022; Shen et al., 2021).

Research on the dynamic interaction of load with selective attention was prompted by the onset of the Load theory of Selective Attention by Lavie et al. (2004). Objective generalizations from the load theory of selective attention claim that the additional occupancy of Working memory (WM) resources of participants during attention task performance might significantly interact with attention performance (Brockhoff et al., 2022; Murphy & Green, 2017; de Fockert et al., 2001). This additional occupancy of WM resources is manipulated by complexity in task or/and instruction design and experienced by participants as load, which has been categorized as WM load (WML). Another type of load discussed in this theory is named as perceptual load, which relates to the perceptual properties of the target and its vicinity. In recent decades effect of WML on selective attention has been published widely but largely revolved around its effect on distractor or irrelevant stimuli processing, a crucial aspect of selective attention (Brockhoff et al., 2023; Simon et al., 2016). Distractor processing research under higher load conditions showed that the higher perceptual load enhances the spatial focus of attention whereas higher WML defocuses the spatial focus of perceptual resources (Lawrence et al., 2020; Linnell & Caparos, 2011). It led to the inquiry of spatial attention, which is the focusing of attention on specific locations under dynamic load conditions. This chapter targets the effect of WML.

Orienting Attention and Working Memory Load

Repeated interaction of WML with distractor processing perhaps, led researchers to extend their research to assess the effect of WML on spatial attention and processes related to it. Load's effect on orienting or spatial attention has been reported in a few replications showing significant effects of WML on molecular orienting behavior or different components of the orienting attention process. The significant effect of WML on Lane-keeping Performance in simulated driving research has been reported as the affected molecular orienting behavior. And, delayed onset of cued orienting, longer reaction time, and compromised accuracy with increasing WML have also been reported recently.

WML influences orienting in multiple ways depending on the kind of WML and orienting aspect we are looking for. Generalizations that emerged out of recent research echo mixed findings but keen observation of methods and results suggest some patterns. WML can be verbal, spatial, and episodic in different amounts and through different sensory modalities. Similarly, researchers are looking for different aspects of orienting attention such as initiation, reaction time, accuracy, etc. The boldest pattern emerged from recent experiments to confirm the shared cognitive resources hypothesis and denial of the absolute automaticity of orienting attention. Initially, orienting was claimed as an automatic phenomenon when a small increase in WML failed to influence the orienting to peripheral pop-out (Jonides, 1981; Pashler, 1991; Santangelo et al., 2008). But later, it revealed that perhaps due to attentional set priority or task instructions, participants prioritize orienting over secondary task performance, which procured the performance of primary task, i.e., orienting attention task. The research resulted in affected orienting due to WML share a common feature of the comparatively large amount of load induced by tasks, which indicates that orienting to a cued target only is a task of low load in itself, and remains an automatic process in either low WML task conditions or conditions of cueing, using highly salient stimuli as cues which increases orienting priority, such as, pop-up in the periphery.

Later, a pattern in fundamental research discusses the quality of orienting attention or attentional focus of perceptual resources to a cued location in a manipulated WML condition. Deterioration in perceptual focus with increasing WML has been reported by other researchers (Caparos & Linnell, 2010; Linnell & Caparos, 2011), which perhaps resulted from the sharing of attentional control resources needed to focus with resources utilized by the WM task (de Fockert et al., 2001; Oberauer, 2019). Linnell and Caparos (2011) examined the interactive nature of orienting attention to another dimension and claimed that perceptual load and WML exert interactive effects on the orienting of attention. Precisely, the defocusing effect of WML was only observed in high perceptual load conditions, not in low perceptual load conditions.

Other patterns of the effect of WML on orienting emerged from applied research on driving. Driving researchers try to generate results in rather higher ecologically valid conditions than fundamental or theoretical research. The need to understand orienting in abnormally load-exerting environments is pushed from driving research, which reports driving errors, leading to accidents that sometimes become fatal.

Orienting in Driving

Initially targeted aspect of orienting attention in driving research was lane keeping, which involves correct detection of turn signals/cues and appropriate response to cues for keeping the car in the designated lane. This molecular behavior largely depends on orienting was assessed by Ross et al. (2014) who instructed their participants to perform a lane-changing task (LCT) in different WML conditions. Behavioral results suggest that increasing WML would degrade the lane-changing task performance, as slowed initiation of lane change, reduced correct lane change, and increased mean deviation in change have been reported in high WML conditions. An additional analysis suggests that degradation in LCT performance was only reported in individuals with lower working memory capacity (WMC) and intact performance was reported among individuals with higher WMC. With similar paradigm but contrary results, i.e., enhanced lane-changing performance with increasing workload has been reported later by Ross et al. (2018), which might have resulted from strict adherence to lane-changing instructions or attentional set priority. This enhancement in lane-changing performance utilized additional cognitive control resources, which was indicated by a significant positive correlation between lane-changing performance and error rates on WML tasks (i.e., the secondary task) (He et al., 2014). These studies propose a hypothesis that during high WML conditions, participants compromise in their attentional control performance on either task and performance on the task set as a priority would be procured whereas performance on remaining task/s would suffer either in reaction time or accuracy.

One more aspect of orienting i.e. initiation of orienting and its related electrophysiological activity of participants in high and low WML conditions, imposed by driving/simulation conditions or through secondary tasks assessed in later studies, and found significantly affected. For checking the electrophysiological markers of this effect, Vossen et al. (2016) utilized a more ecologically valid driving simulation of a traffic scene with manipulation of WML through holding and operating auditorily presented digits. ERP data analysis showed the delayed initiation of orienting response in high WML conditions in comparison to low WML conditions. In further replication, Ross et al. (2018) brought a few additional changes to enhance the ecological validity of the testing procedure applied by Vossen et al. (2016) and reported contrary results, i.e., the absence of delayed initiation of orienting-related electrophysiological activity of the brain during task performance. One more aspect of orienting found affected in high WML conditions reported is sensitivity for target and false alarm for target detection. Vossen et al. (2016) found from behavioral results that in high WML conditions, the sensitivity of participants for target detection was found reduced in comparison to low WML conditions. Similar, trends for reduction in sensitivity for target in high WML conditions were also reported by Ross et al. (2018). Along with reduced sensitivity, increased false alarms in high-load conditions were also recorded which indicates reduced availability of attentional allocation control, due to excessive expense of this capacity for the performance of the secondary task.

There are some other attentional processes about orienting such as inhibition of return, pseudoneglect, and retro cueing. Interaction of these processes individually with WML has also been reported with certain important and meaningful generalizations for research and innovation purposes. *Inhibition of return*, which is observed as the additional reaction time taken by participants to orient to a recently visited location. This has been reported to diminish with the increasing WML. Similarly, *Pseudoneglect*, which is a bias to orient in the left hemifield with better speed and accuracy, has been reported to diminish or shift bias to the opposite direction, i.e., right hemifield, under the conditions of high WML. And, *Retro Cueing* is the cued orienting to a subset of stimulus in a mental representation of a stimuli array in the WM and has also been reported influenced by the presence of high load conditions or complex concurrent task performance. Further, let's look deeper into the recent publications reporting the interaction of these three processes with WML.

Inhibition of Return and Working Memory Load

While inspecting their newly designed paradigm for exploring orienting behavior, Posner and Cohen (1984) observed a phenomenon, named, Inhibition of Return (Posner et al., 1985), later recognized as a foraging facilitator (Klein, 2000). As it is named, participants were found delayed in attending and responding to targets presented on the same location recently visited, compared to targets that appeared on the new location. Inhibition of return has been observed from SOA of 300ms to 3500ms (Hu et al., 2011). Some experiments confirmed the IOR through replications and discussed its nature (Li et al., 2022; Klein et al., 2023) and some also have denied the generality of such a phenomenon (Terry et al., 1994).

Studies affirming IOR, largely discussed its attentional aspect, cause-effect nature, and temporal dynamics using cueing-target and target-target paradigms. Recent reviews support the initial notion from Posner et al. (1985) that oculomotor activations are the cause and response bias against visited locations are effects of IOR. Testing of IOR in two different paradigms, namely, detection and discrimination, reported variations in temporal dynamics of IOR and results suggest that onset is early around 300ms, and sustained longer (up to 1300ms) in detection tasks than delayed onset (600ms or later) and early decay (1000ms) observed in discrimination tasks (Lupiáñez et al., 1997). This difference in detection and discrimination posited a probability that temporal dynamics of IOR can vary due to different task demands associated with both kinds of tasks (Chica et al., 2006; Klein, 2000; Lupianez et al., 2007).

Before focusing on task demand's effect on IOR, let's have a look at some factors that might affect our intended effect (i.e., the WML effect). Literature suggests that IOR is an attentional set contingent phenomenon. Existing or intended attentional sets interact uniquely with cues and targets of the current task and hence affect an individual's cue and target perception, and his/her reaction to it (Folk et al., 1992; Klein, 2000). Along with it, changes in cue type, duration, target type, and duration, and the time interval between the appearance of these two and an individual's WM available for processing of these stimuli might affect the onset and decay of IOR in different paradigms (Zhou et al., 2019; Niimi et al., 2017). A description of these variables has been given because these have affected the load's effect on IOR and are suspected as major factors behind the non-linear nature of findings reported in recent literature.

Now, let's focus on research that studied the effect of task demand or rather specifically, WML on IOR. Castel et al. (2003) instructed participants to memorize digits after the cue and before the target, and IOR was found unaffected, but additional spatial WML eliminated IOR; overall authors reported that memorizing additional spatial WM content can eliminate the IOR, present otherwise. The notion has also been supported by other researchers as well since then (Kahan et al., 2013). As the presence of a spatial WM component in IOR behavior has been suggested by Castel et al. (2003), similarly, verbal WM has also been found to interact with IOR. Memorizing verbal content before cue presentation, in large amounts has been found the probable cause of delay in the onset of IOR (Klein et al., 2006), although few studies have shown that IOR was found unaffected in the presence of increased verbal WML.

Further developments have discussed the generalizability of load's effect on IOR. Zhang and Zhang (2011) pointed toward IOR specific to the response modality, and their results suggested that the effect of spatial WML was limited only to tasks involving manual response, and tasks requiring saccade response remained unaffected even in the presence of increased load. These findings were contradicted later, when Shen et al., (2021) presented their participants with an orienting task along with inducing spatial WML and interpreted their results as the load can eliminate IOR in only detection tasks required saccadic response but not in tasks demanding a manual response from a participant on target detection. Spatial WML does not affect IOR temporal dynamics in visual search tasks has also been reported recently (Höfler & Kieslinger, 2022).

The effect of WML on inhibition of return has been recorded as significantly interacting with attentional sets of participants during task performance. Attentional sets have been evident in influencing the onset of IOR and, sustenance of IOR (Shen et al., 2021; Niimi et al., 2017; Klein, 2000; Folk et al., 1992), in high-load conditions. Shen et al. (2021) interpreted reduced IOR in their results as the outcome of active attentional control set for the WM task and the absence of modulation in IOR as the outcome of active attentional control set for the cueing task. Along with being evident in IOR modulation, the Attentional control setting has also been evident in modulating distractor processing in selective attention tasks in conditions of higher WML and perceptual load (Chelazzi et al., 2019). The recurrent appearance of ACS in discussing results of attentional phenomena indicates signals for incorporation of it as a significant variable in our research planning and keeping our eyes wide open for seeking possible manipulation of these and its effect on the number of dependent variables commonly taken in attention research.

Pseudoneglect and Working Memory Load

The concept of pseudoneglect originated from clinical research, through exploring and confirming hemi spatial visual neglect. Problems in visual perception of stimuli/targets in the hemispace contralateral to the damaged hemisphere were reported in multiple studies from the onset of the 20th century (Holmes, 1918; Riddoch, 1935). Holmes (1918) studied 6 individuals with visual perception impairment who sustained injury in one or both hemispheres. Symmetrical bias, reported as reliable in healthy participants, gained ecological validity after, participants showed leftward bias in natural pictures' free-viewing (Nuthmann, & Clark, 2023; Chiffi et al., 2021). Although multiple studies have reported leftward bias using different tasks, similar to other cognitive phenomena, pseudoneglect has also been found to vary with individual differences, sensory modalities, and task types. Mitchell et al. (2020) tested tasks of different modalities and reported evidence that supported the sensitivity of pseudoneglect with task types and modalities. Harvey et al. (2002) categorized neglect in terms of perceptual and premotor neglect and found that both types exist in each patient's neglect but in varying proportionality. The absence of any systematic pattern in varying proportionality led authors to refrain from any generalization over it but additional analyses suggested that task difficulty was a suspected variable that might affect observed neglect. Later research supported that healthy individuals show leftward bias in the horizontal plane, which was found sensitive to the WML. Results indicate that increased load attenuated leftward bias and shifted bias rightwards (Ciricugno et al., 2021; Paladini et al., 2020; Naert et al., 2018); as it attenuates with increasing age (Chiffi et al., 2021). Naert et al., (2018) ruled out the possibility of handedness in pseudoneglect and reported that the strength of load experienced by participants determines the intensity of bias in participant's performance.

The presence of symmetrical bias in the vertical plane is also reported among healthy individuals (Chapin et al., 2022). Similar to horizontal asymmetry, research showed that WML reduced symmetrical bias towards upper hemispace, in the vertical plane (Ciricugno et al., 2021). In a study focusing on visuospatial cued orienting, WML manipulation increased WML which led to decreased target sensitivity with no change in response bias (Vossen et al., 2016). These results indicate that visuospatial orienting tasks utilize similar cognitive resources, which are also utilized by WML-inducing tasks.

So, these studies indicate that pseudoneglect as a concept has been found reliable through multiple kinds of research, but for sound generalization regarding the existence of pseudoneglect, testing individual differences and modality-specific differences, well-controlled research needed to be carried out. The interaction of WML with pseudoneglect has also been echoed in recent research. Further, experiments would help us understand the orienting of attention, as a molecular behavior, in different contexts.

Retro Cueing and Working Memory Load

Multiple studies in recent literature have claimed that retro cueing has an interactive relationship with working memory load. Orienting to internal representations also known as retro cuing has been found sensitive to WML. Initially, Griffin and Nobre (2003) revealed that the cost and benefits associated with pre-cueing to the external environment were similarly taken place in internal orienting. This was obtained through modification of the existing Posner paradigm for external orienting assessment, with the introduction of retro-cue (Nobre et al., 2004). In Retro cue conditions, a cue appears after the stimuli array and the cue indicates a location from the passed stimulus array for the correct target for that trial, in the valid cue conditions. This orienting to the items held in WM strengthens the notion of WM's interaction with attentional processes, which was also pointed out in different hypotheses evolved in cognitive psychology (Cowan, et al., 2024; Oberauer, 2019; Baddeley, 1996). Storage, rehearsal, and orienting attention to the information within WM have been shown in these studies. Interaction between information from LTM regarding features of the stimuli pattern or the plan made of it (or attentional set) and the orienting to the target from the current task has also been reported repeatedly, discussed under the contingent orienting hypotheses (Folk et al., 1992; Pratt et al., 2001; Corbetta & Shulman, 2002). This led to the next question, whether information set from outside instead of LTM, either semantically or capacity-wise, can interact with orienting for the target present in the stimuli array in the internal WM environment. Few experiments reported that the retro cue effect is rather automatic or utilizes independent cognitive resources as this effect has been found intact from the interference that might have occurred with secondary tasks performed with internal orienting tasks. The absence of interaction with the secondary task has been reported with the visual search task (Hollingworth, & Maxcey-Richard, 2013), color classification task (Rerko et al., 2014), and digit classification task (Makovski, & Pertzov, 2015). Interaction between WML imposed by additional information processing or compelled by the external environment, and orienting to stimulus array in WM was found to be significant, in another line of research (Janczyk, & Berryhill, 2014; Chun et al., 2011; Lepsien et al., 2005). One significant finding resulting from these experiments is that load's effect on attention or visual search performances was found attenuated after orienting to the stimuli array present in the WM (Taylor et al., 2023; Souza et al., 2014). This load-effect attenuation through orienting to WM can play a vital role in instruction design, but poses serious research questions such as, what amount of load can vanish, up to what level, and does it also make performer resistant to the load further in the task? (Souza & Oberauer, 2016; Zerr et al., 2021). Later researchers discussed the load's effect on orienting to an internal stimuli array and reported mixed results (Janczyk & Berryhill, 2014; Krefeld-Schwalb, 2018; Lin et al., 2021; Rerko et al., 2014). Krefeld-Schwalb (2018) claimed the presence of retro cue benefit, irrespective of load but failed to observe attenuation of load after cued orienting or securing the cued target location and object, from their experiments. Matsukura et al., (2007) in experiment 3 showed that due to increased load from 4 to 6 items in set to be remembered till probe, the accuracy of orienting to representation was found significantly reduced in high load conditions than in low load conditions. Reaction time analysis reported by Lin et al., (2021) suggests that orienting to WM stimuli array representation interacts with load experienced by participants due to dual-task performance, hence, a reduced retro cue effect was observed in high load conditions in comparison to the low load condition of the single task only. This interaction was also reported previously by Janczyk and Berryhill (2014) reported interaction if tone discrimination as a secondary task was introduced during memory set retention interval but with a suspicion that this interaction might have resulted due to response overlap between orienting task and secondary task execution. But later, Lin et al, (2021) denied this possibility, as found load effect was also sustained in no-overlap conditions and reported that the effect is also sensitive to articulatory suppression along with response overlap. The reduction in retro cue effect was observed larger in response overlap conditions and a little shorter in no-overlap conditions. This interaction in dual-task conditions between response proximity of both tasks and task performance strengthens the notion that the retro cue effect is not an automatic or independent cognitive phenomenon and that concurrent tasks in multitasking scenarios affect it. The absence of a reduction in retro cue effect due to load increase might have been due to more than enough duration being given for processing stimuli from both tasks.

This replication of reduced retro cue effect in the proximal presence of concurrent task of significant load, suggests future studies objecting to study the effect of well-defined parametric manipulation of loads on orienting to the mental representations in WM.

Summary and Future Directions

In summary, recently published literature has reported the significant effect of load on spatial behavior. Increased WML has been found to slow the orienting attention to the external world with poor perceptual focus, to reduce the inhibition of return and pseudoneglect, and to reduce the accuracy in retro cueing. Advancement in fundamental knowledge refined through theoretical research regarding spatial attention would help us in detecting and assessing the inability present in any clinically suffering individual or any individual's need of scaffold for peak performance (Chaurasia et al., 2020). And also, for designing informed and reliable training modules such as *Attentive Kindergarten*, *Computerised Progressive Attentional Training*, and client-centered modules for cognitive training of specific attentional skills. Application of these cueing techniques & spatial attention knowledge-laden interventions have proven efficient in certain rehabilitation programs and educational curriculums (Palacios-Navarro et al., 2016; Edmans et al., 2000). For example, collision studies have found that the degree of pseudoneglect was positively correlated with collisions from objects present in the right hemifield (Hatin et al., 2012). And, studies assessed pseudoneglect under WML suggest that increasing load can attenuate the bias presented otherwise or turn it in the opposite direction, i.e., right hemifield. This can be tested in driving research if manipulation of WML on occasions that are prone to collision from objects coming from the right hemifield. Further, reviews of these techniques have suggested the testing of these spatial attention skills across individual differences and different contingencies of task nature (Pittaras et al., 2022). Understanding spatial attention dynamics under varying load conditions would partially be a supply to such demands, as we have seen in applied cognitive psychology literature that the load imposed by task has been recognized as an important variable.

The present article aggregated the notion that load can significantly affect spatial attention behavior, but mixed findings and lack of replications hinder us from reaching bold generalizations. It suggests that spatial attention behavior should be tested in different contingencies of different types of loads, such as working memory load and perceptual load.

Further the present literature review claims the significant interaction of load with phenomena related to spatial attention behavior but with few replications. It suggests to us that orienting studies with WML and perceptual load must be done to strengthen generalizations regarding it. Along with load variation, testing of spatial attention with different sensory modalities and load pertaining to different cognitive faculties should also be done. In line with the Resource capacity model, multiple studies with shorter load variation specifically in cognitive faculties, which are not utilized in spatial behavior, failed to observe any significant effect of load. Thus, future studies should manipulate load in larger and parametric variations to test its effect on attentional behavior. Further, it has been found in multiple clinical or healthy groups that orienting attention has an interactive relationship with other attention performances such as alerting and executive attention (Rai et al., 2023; Rai et al., 2017). Asanowicz & Panek (2020) suggest that a certain amount of alerting attention activation is necessary for performing orienting behavior. Thus, we suggest that future studies should incorporate the Attention Network Test model (Fan et al., 2002) for a comprehensive understanding of orienting attention, and its interaction with alerting and executive attention network performance. Along with the addition of fundamental knowledge of human behavior, these researches would also help us in understanding and predicting human behavior, such as how people learn, drive, read, etc., under load conditions.

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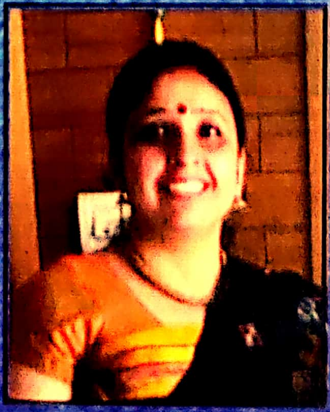

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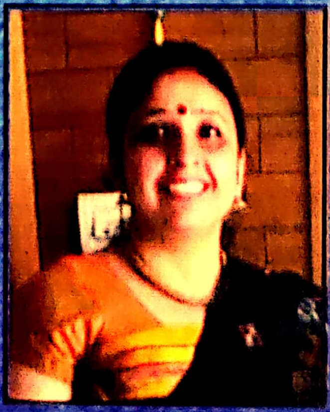

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